Course B: Superconductive RF

T. Saeki (KEK)

LC school 2013

5 - 15 Dec. 2013, Antalya, Turkey

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Cavity Fabrication

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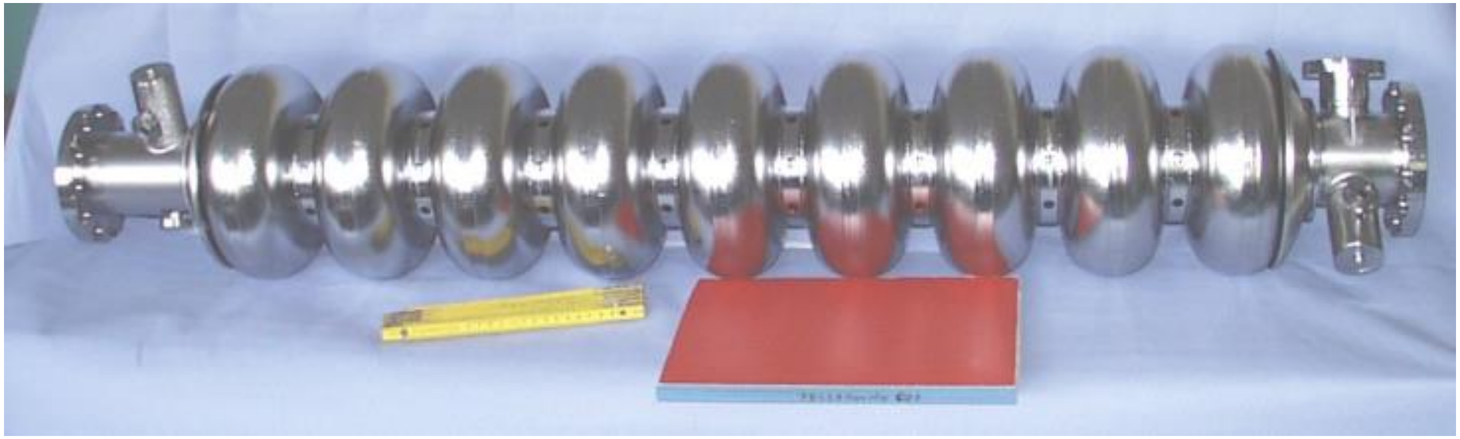
LC school 2013

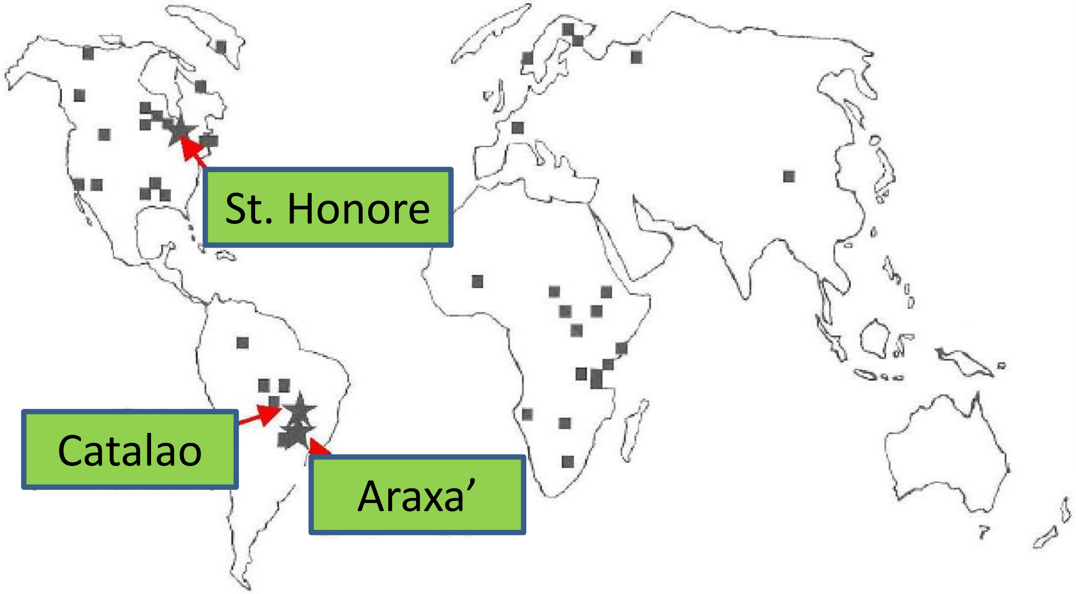
10 Dec. 2013, Antalya, Turkey

1.3 GHz elliptical 9-cell cavity



TESLA 9-cell Cavity
(Iris 70 mm)

Nb Mines in the world



Ore of Nb:
Carbonite

Three largest mines in the world:
Araxa'
Catalao
St. Honore

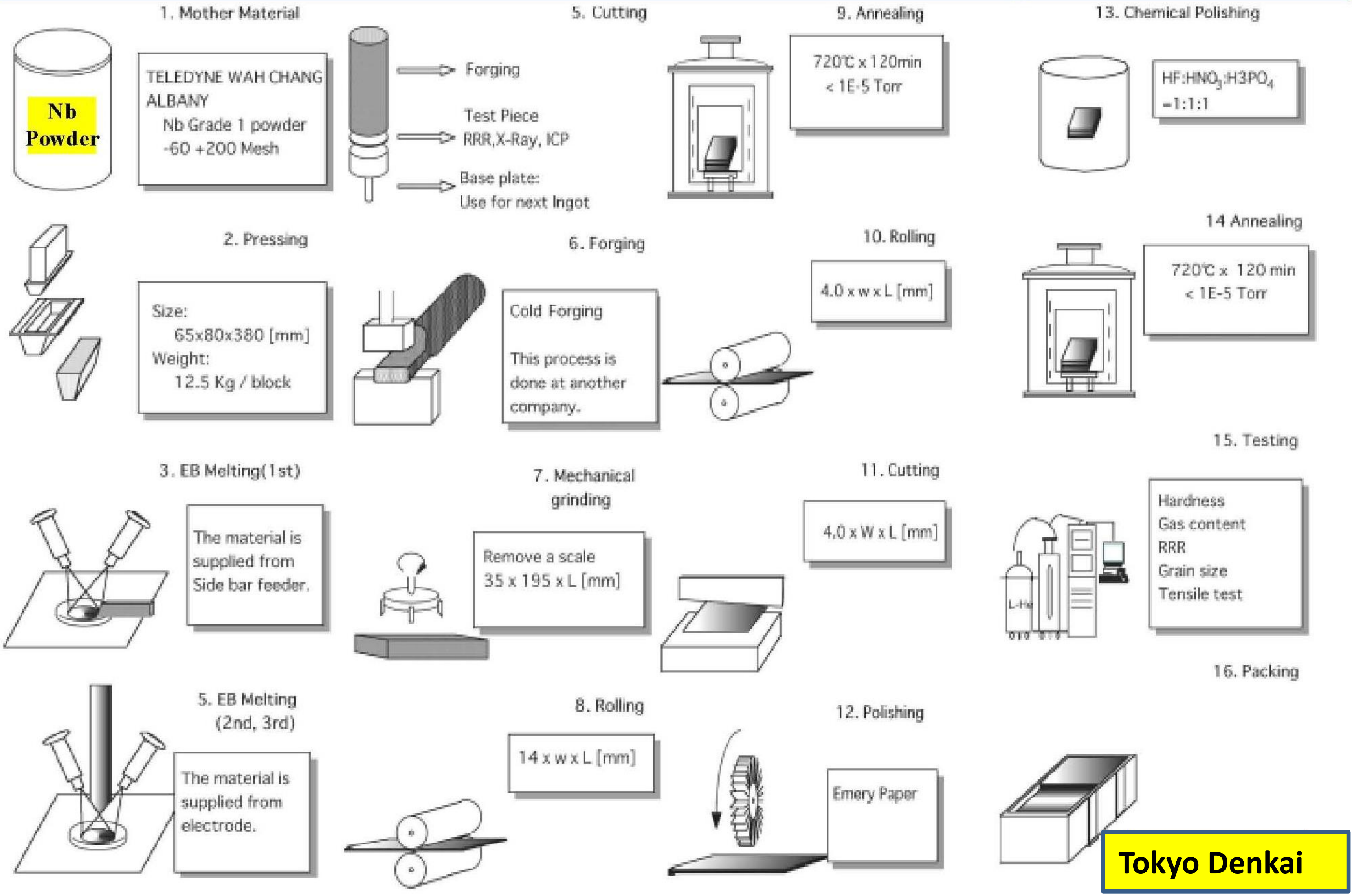
■ Nb deposits
★ Nb Mines

金属 Vol.72 (2002) No.3

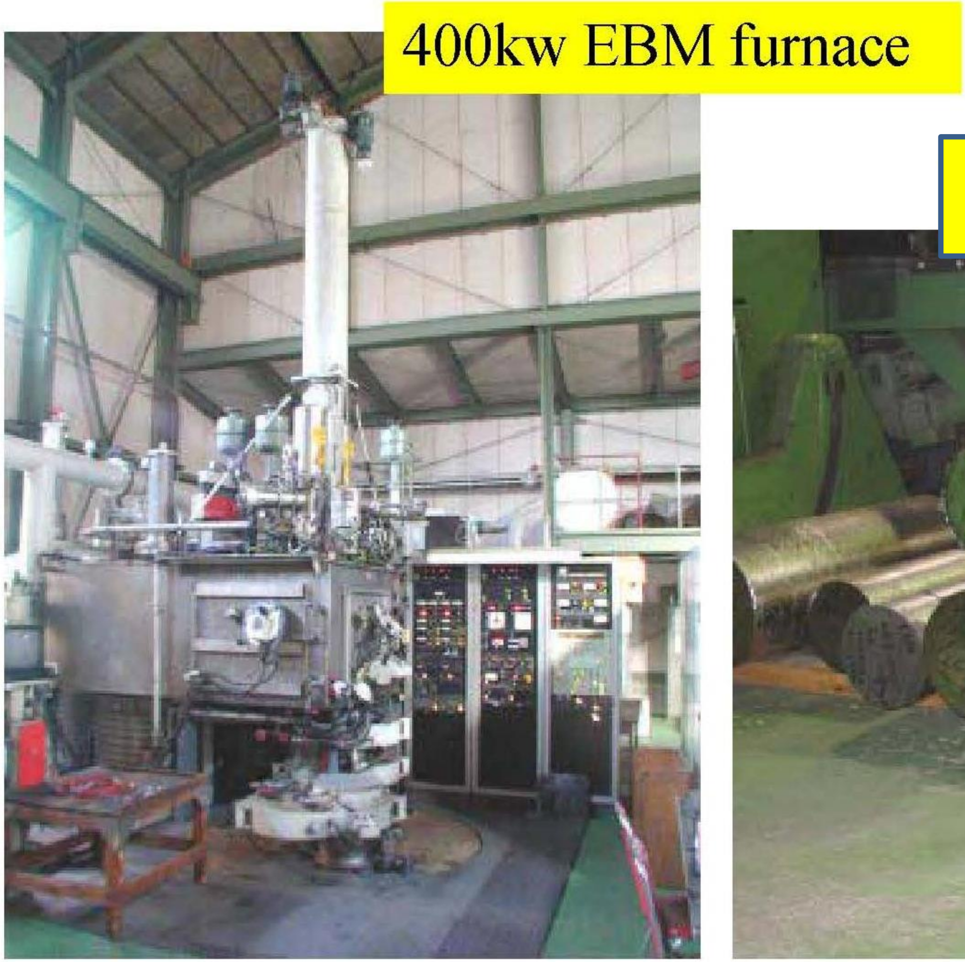
Niobium is the 33rd abundant/rich metal in the all existing metals in the earth.

Nb Mine

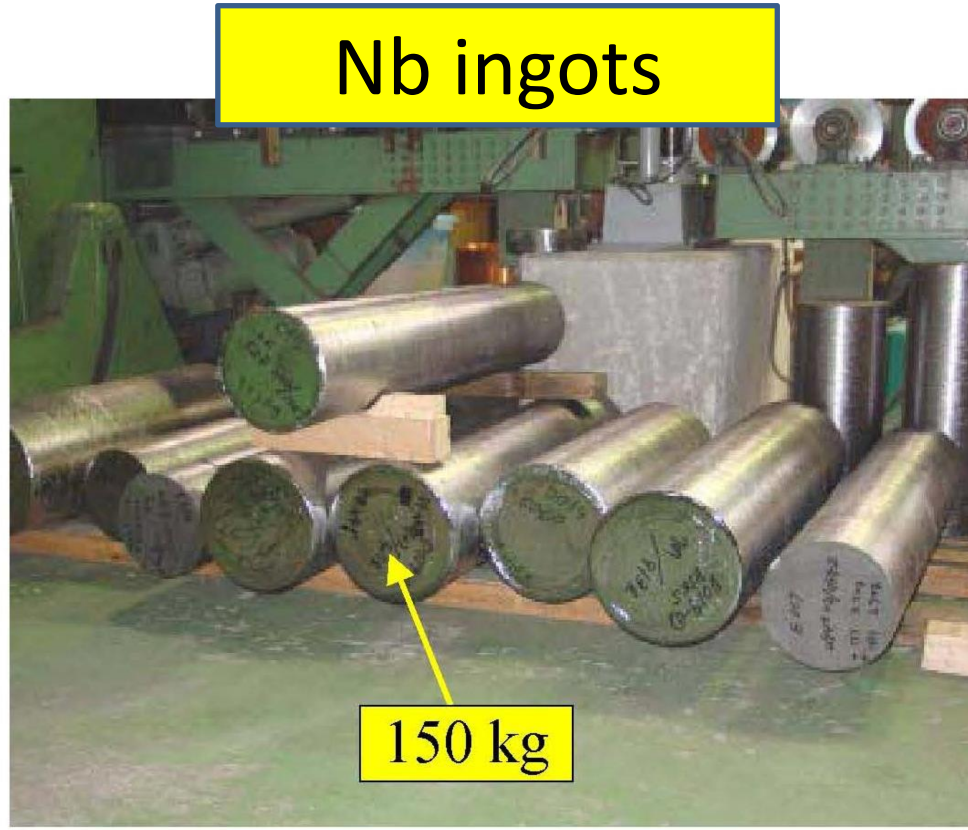
Process flow of the industrial Nb production



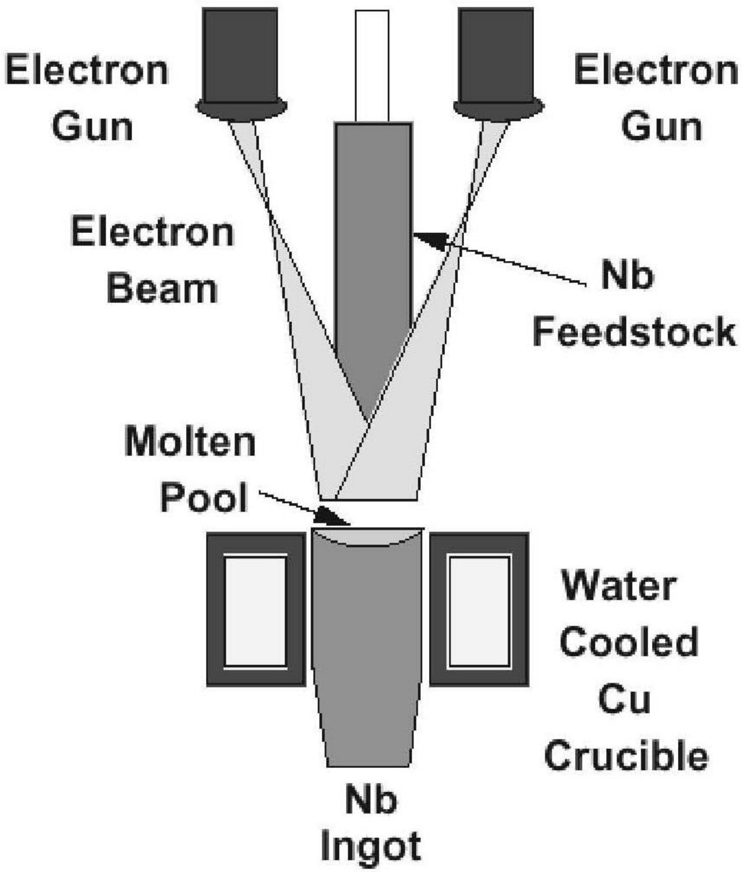
Electron Beam Melting (EBM) Furnace and Nb Ingots



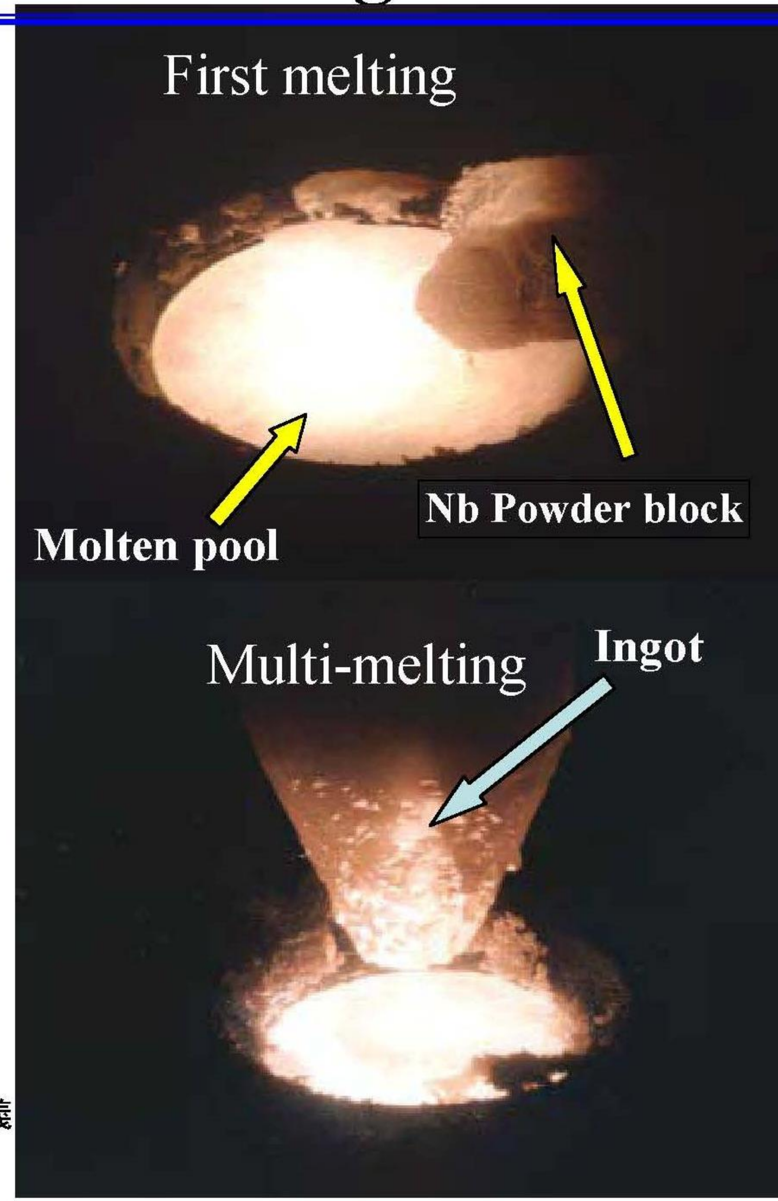
Tokyo Denkai



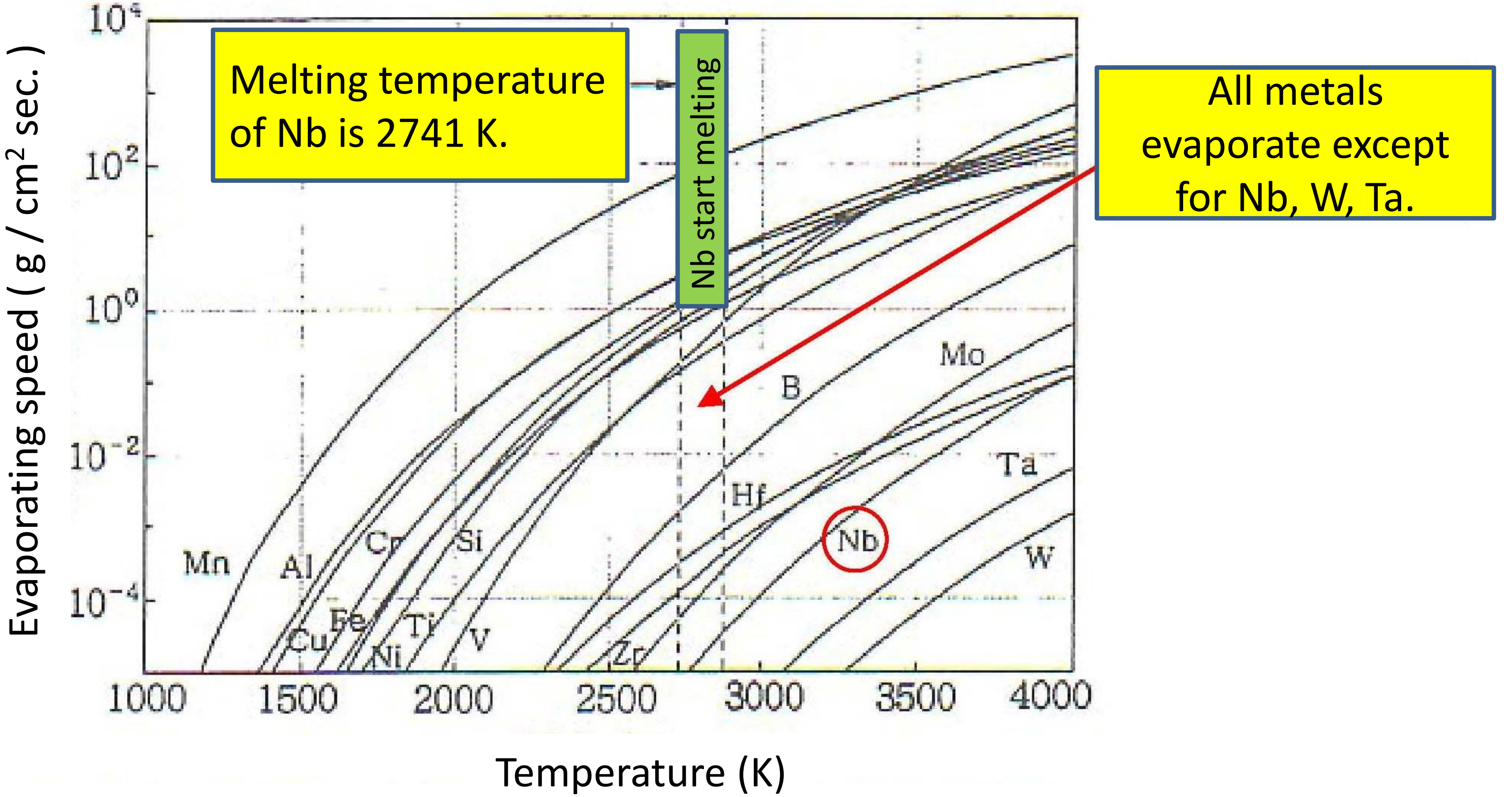
Electron Beam Melting



講義



Evaporation Pressure of Various Metals

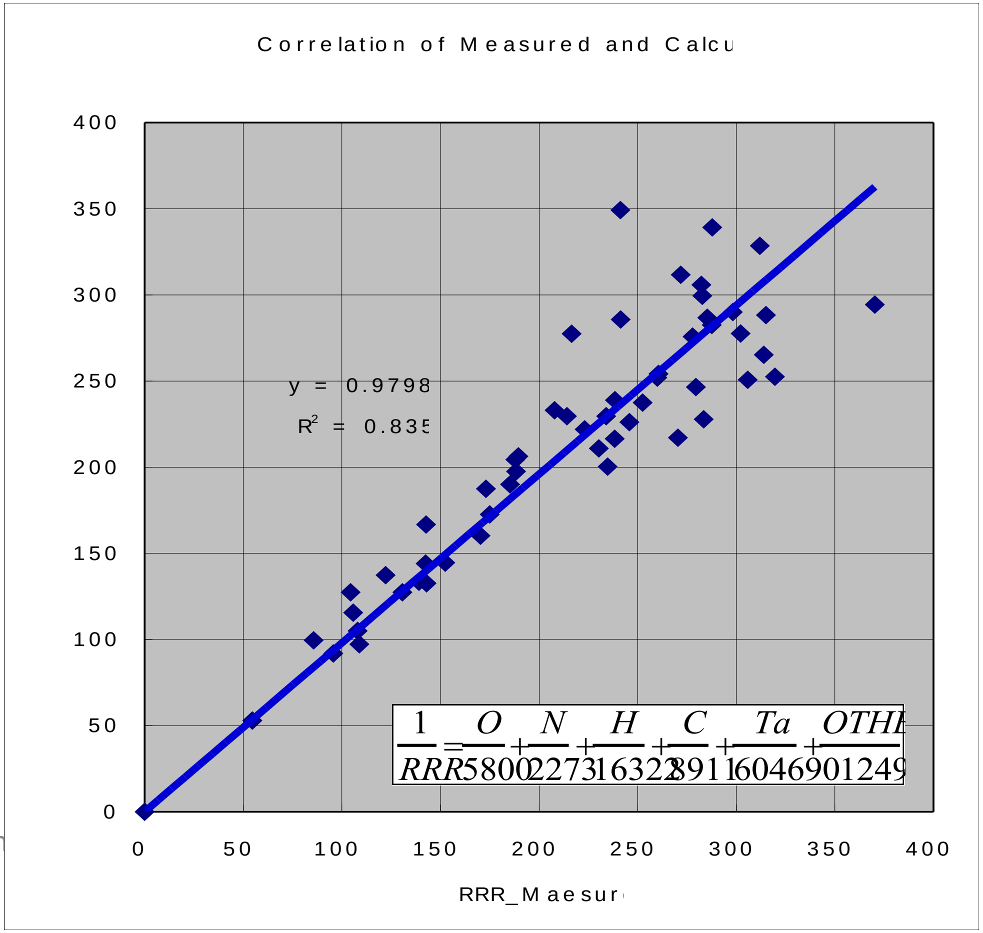


Relation between impurity in NB and RRR

Umezawa's calculation.

$$\frac{1}{RRR} = \frac{O}{5800} + \frac{N}{2273} + \frac{H}{16322} + \frac{C}{8911} + \frac{Ta}{604690} + \frac{1}{1249}$$

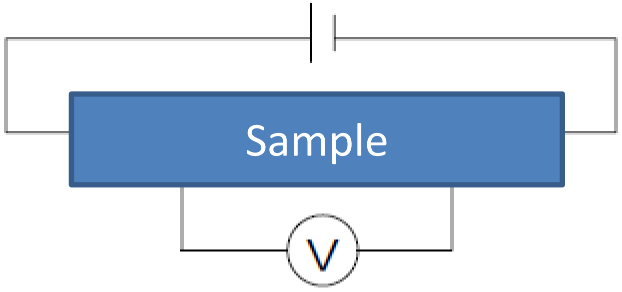
$$RRR \equiv \frac{R(300K)}{R(9.5K)}$$

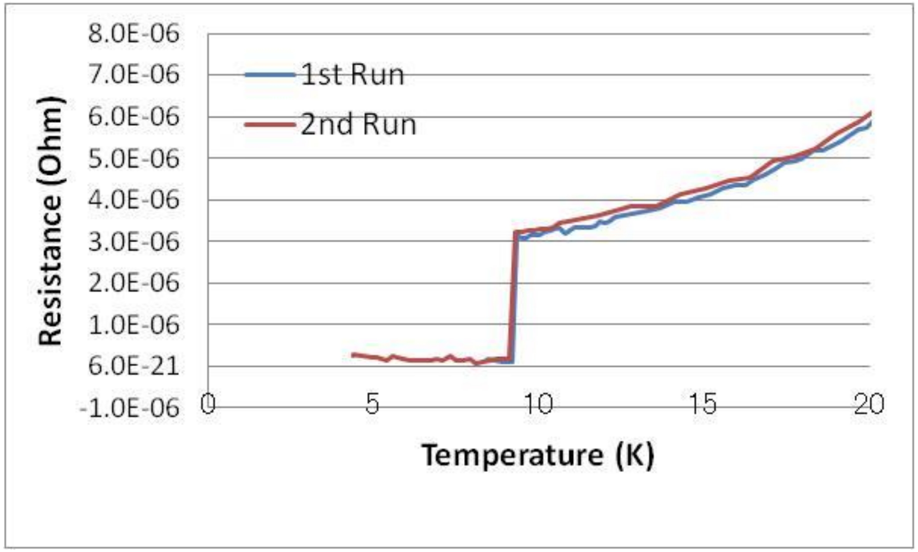


RRR Measurement

$$RRR \equiv \frac{R(300K)}{R(9.5K)}$$

4-terminal method





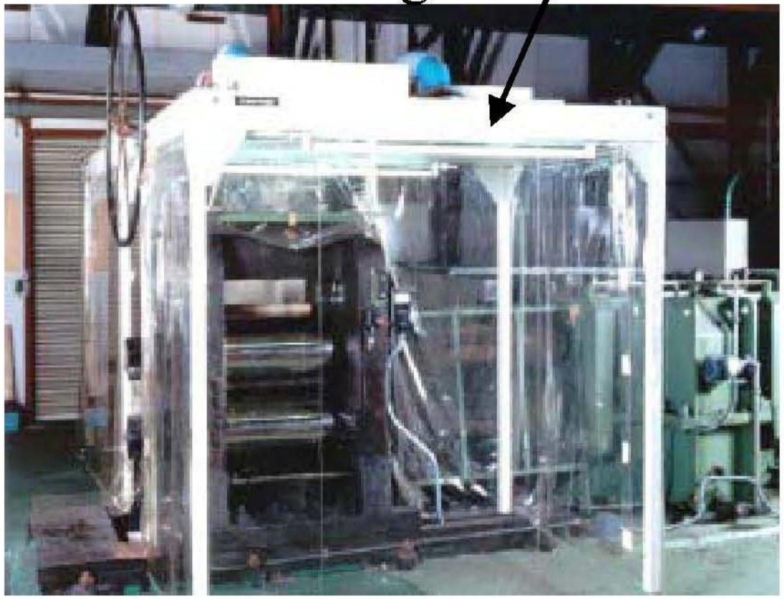
Rolling of Nb plates

Tokyo Denkai

Intermediate rolling

Clean room

Final rolling



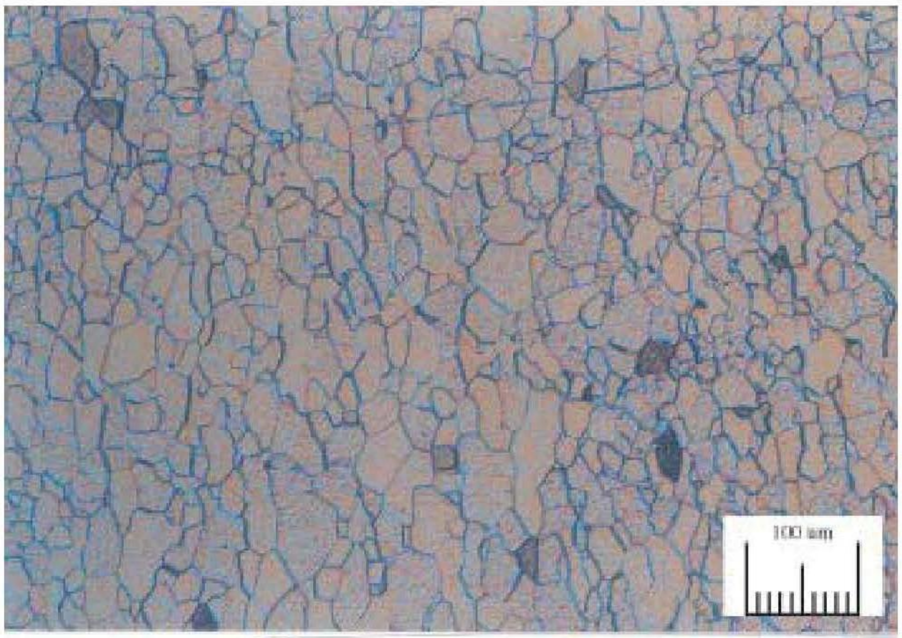
It is very important to avoid any contamination when rolling Nb plates.

Vacuum Annealing Furnace

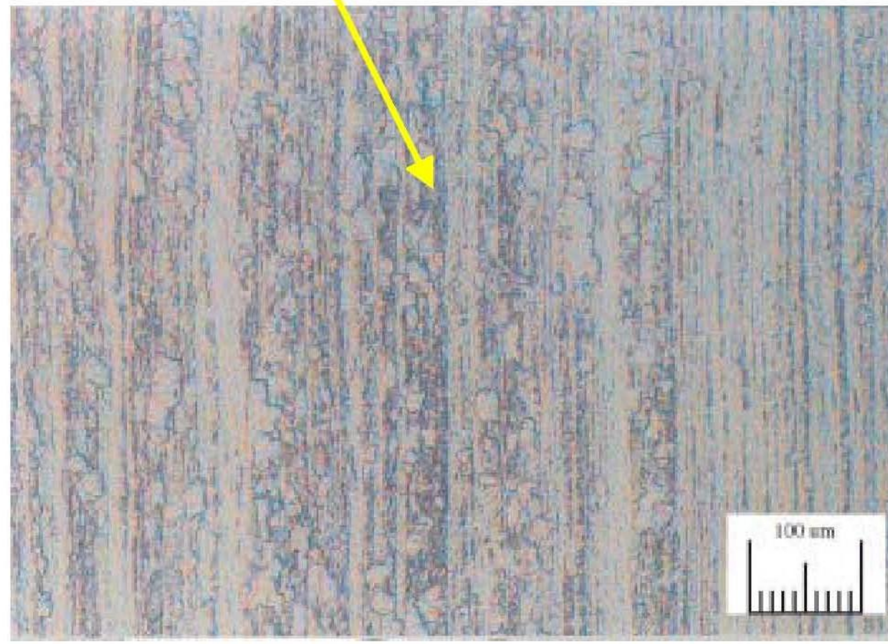
Tokyo Denkai
1400^{o}C Max,
~$1x10^{-6}$ Torr
Effective working zone
1000 x 1800L
Ta heater

Nb metal structure

Layer structure caused by rolling

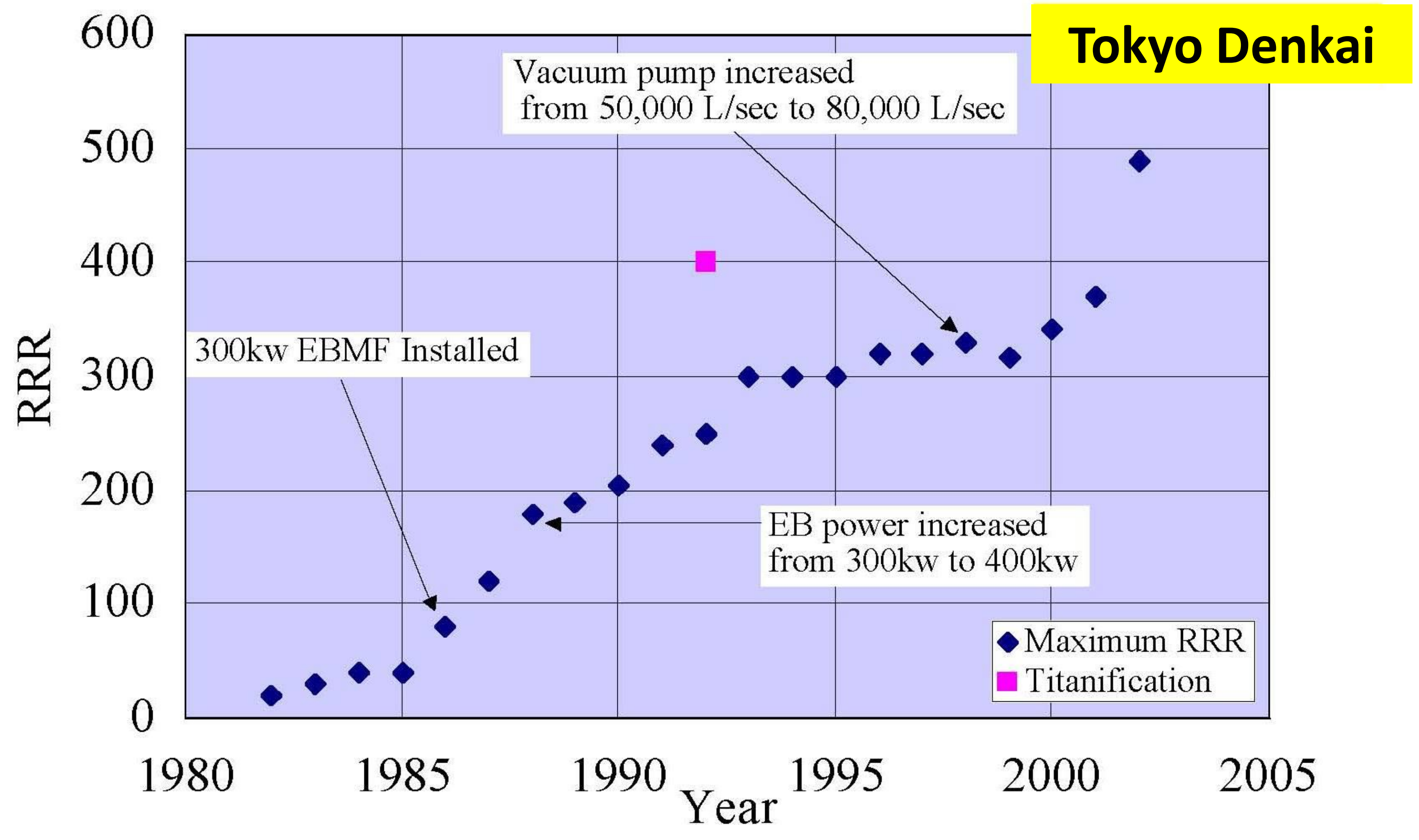


After annealing process

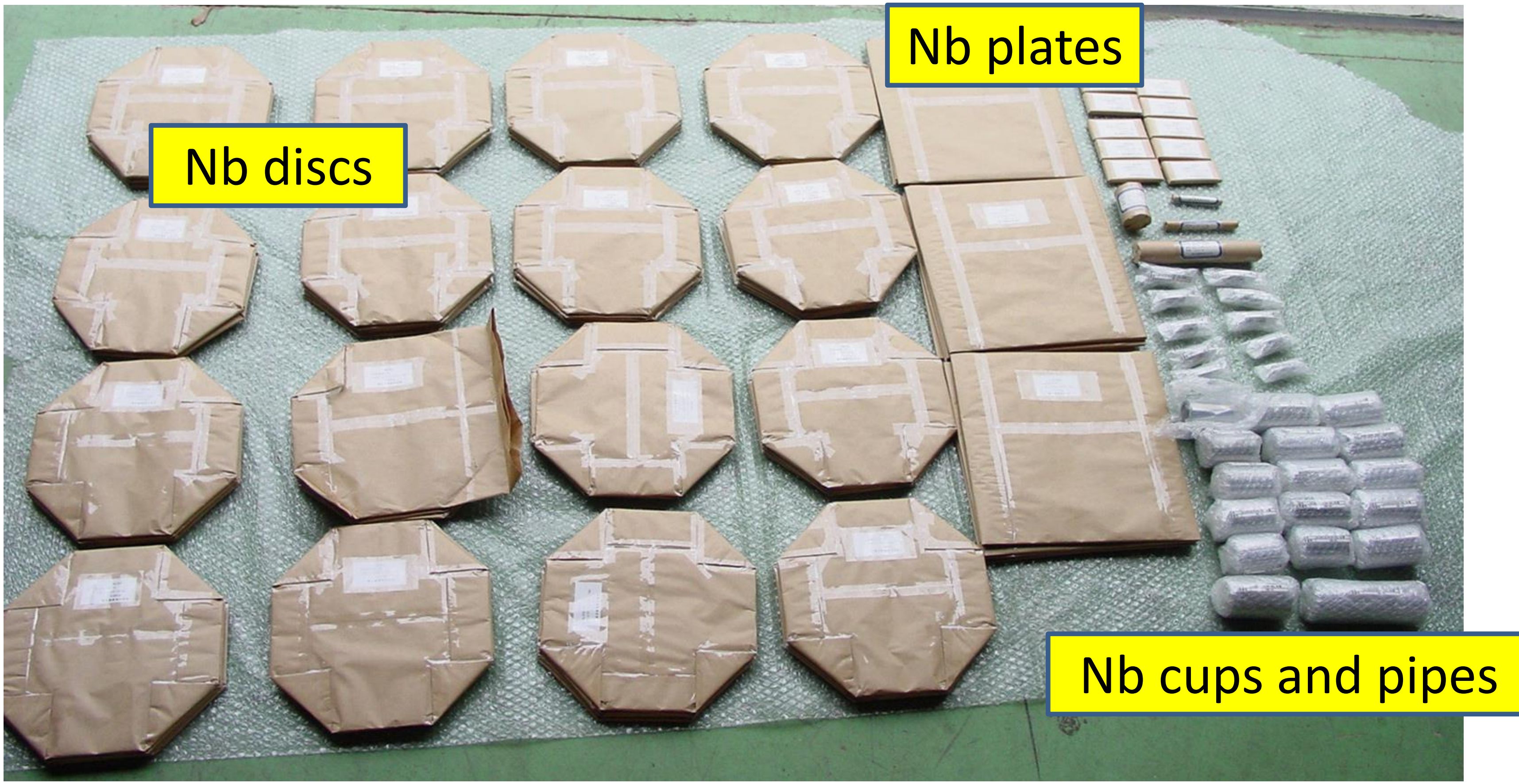


Before annealing process

History of improvement with RRR



Nb materials for 9-cell cavity



Material for four 9-cell cavities

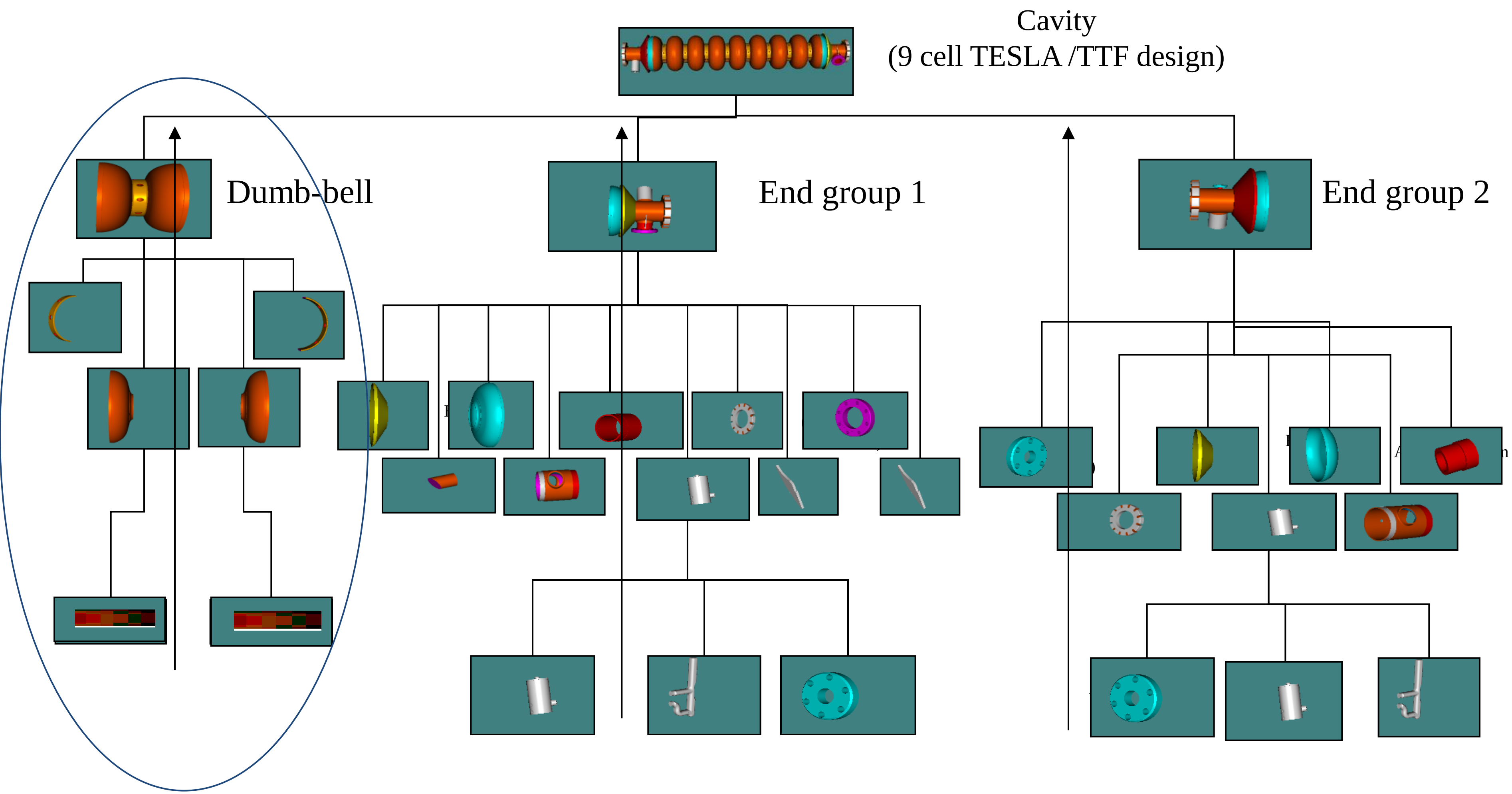
Nb materials for 9-cell cavity

Nb plate for beam-pipe

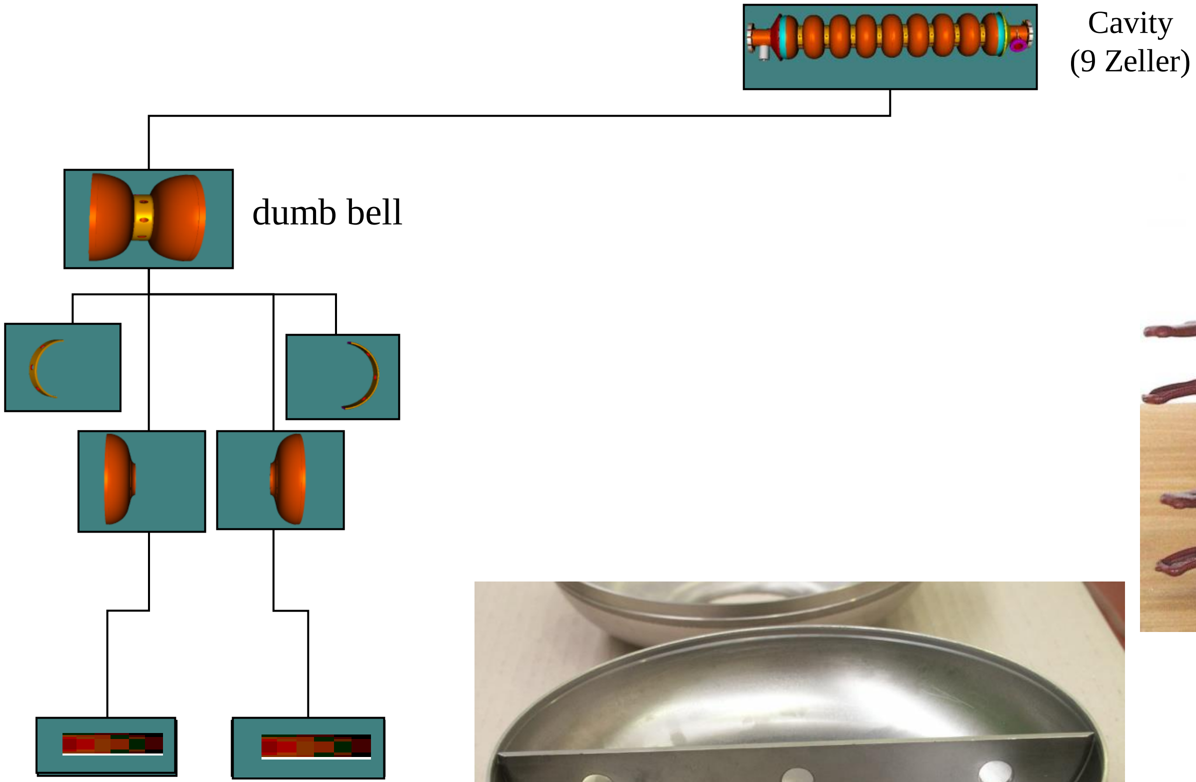
HOM antenna and so on

Nb disc for half-cell cup

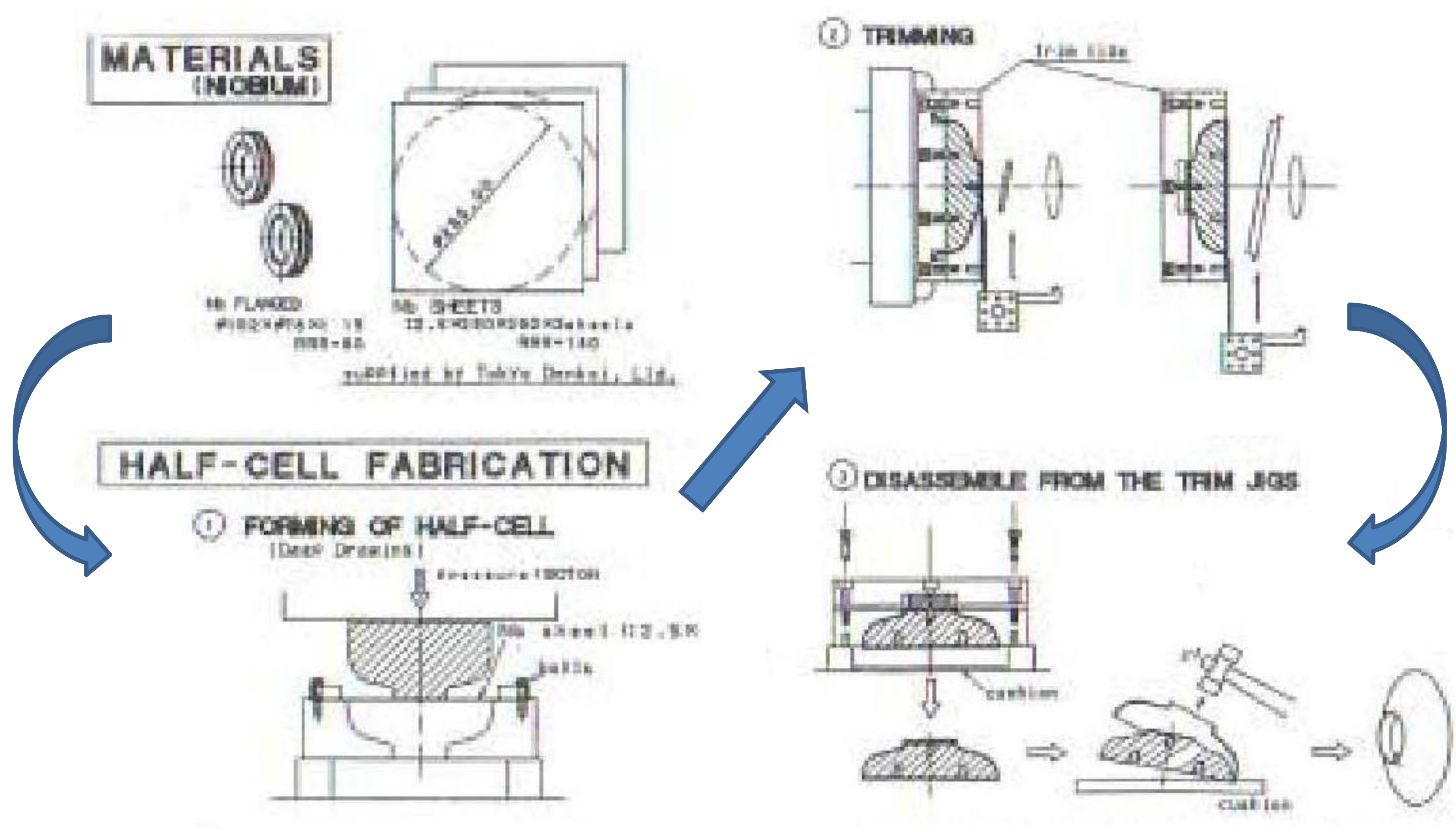
Overview over Fabrication of 9-cell cavity



Overview over Fabrication of 9-cell cavity

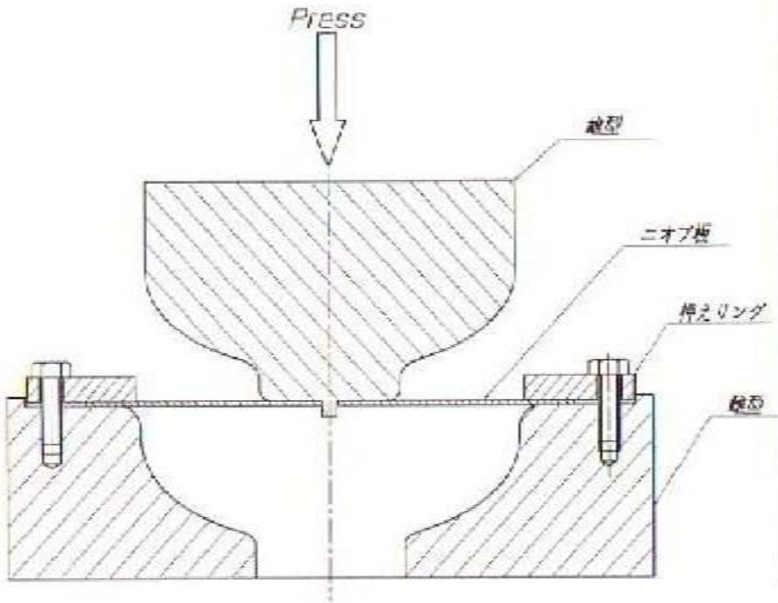


Fabrication Processes of half-cell



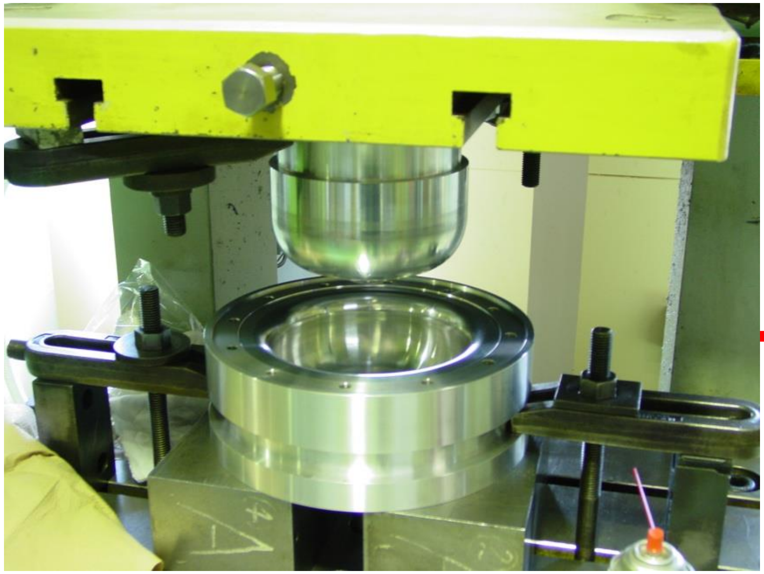
Deep-drawing of half-cell cups

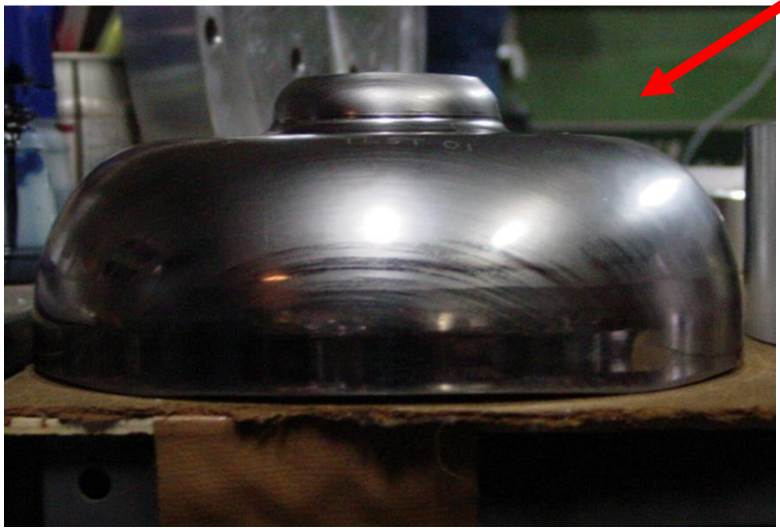
Deep-drawing of Nb half-cell at 2.5 ton by a press-machine (80 ton).



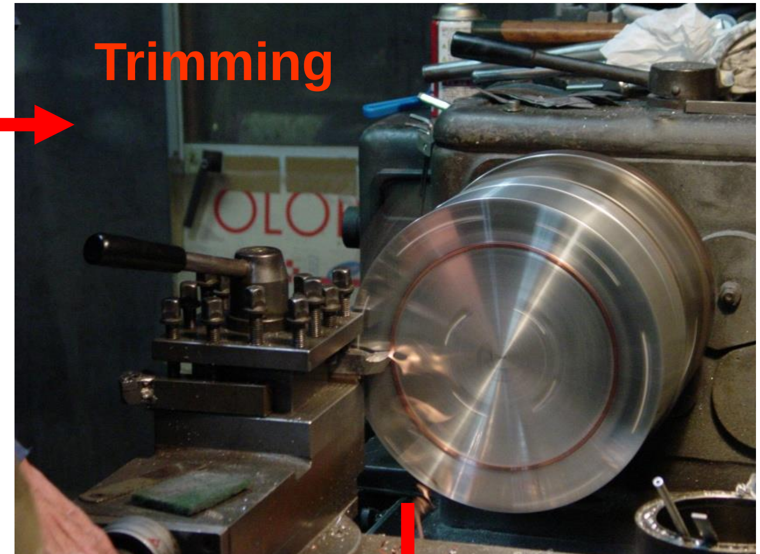
Fabrication of LL Cavity at KEK

Pressing Nb plate **56 half-cells were pressed in a few hours**



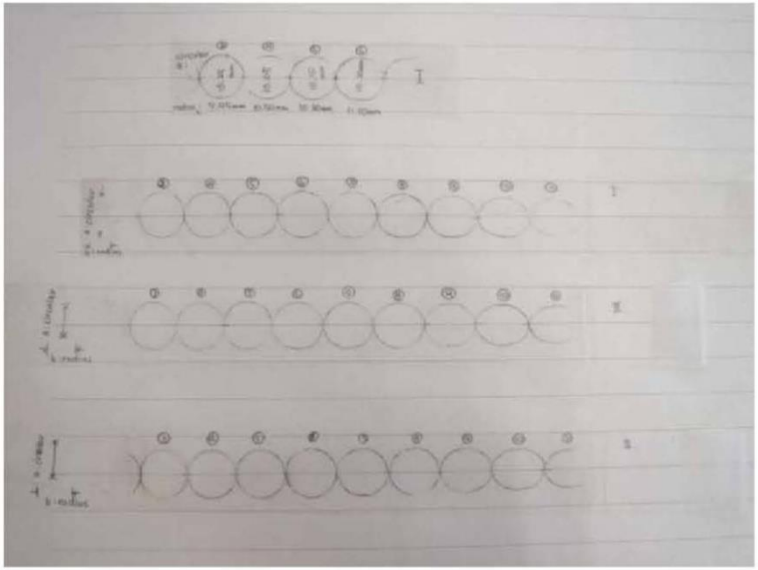


Fabrication of LL Cavity at KEK

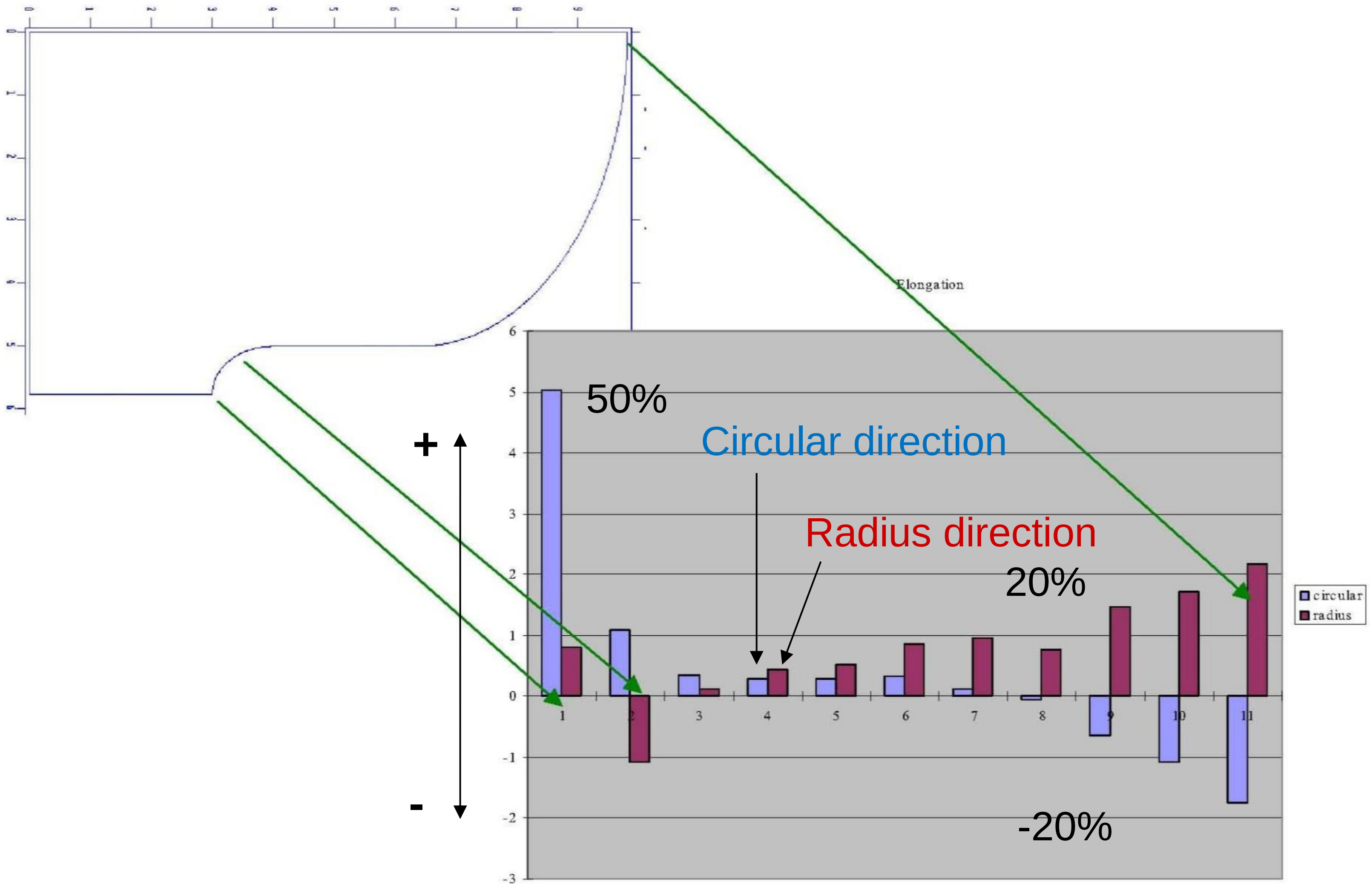


After trimming

Elongation Measurement



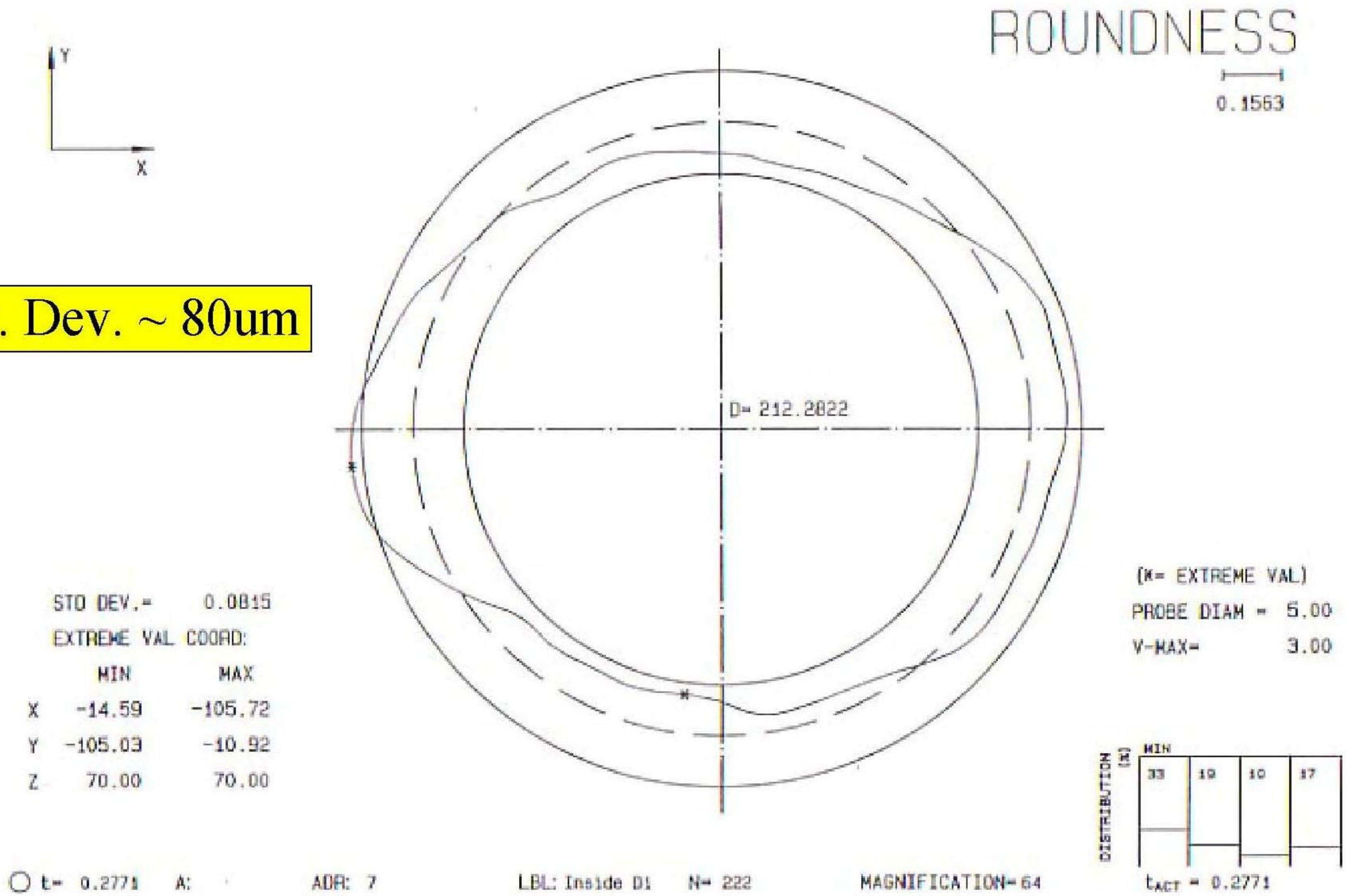
Elongation



Elongation
50%
Circular direction
Radius direction
20%
-20%
+
-
circular
radius

Roundness of half-cell cup

Stn. Dev. ~ 80um

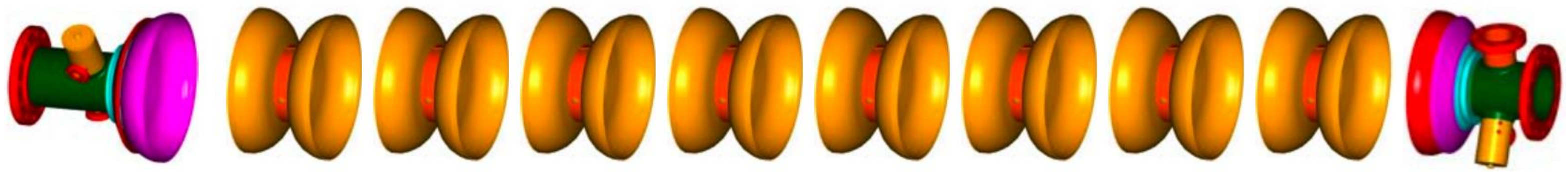


Production procedure of 9-cell cavity for ILC

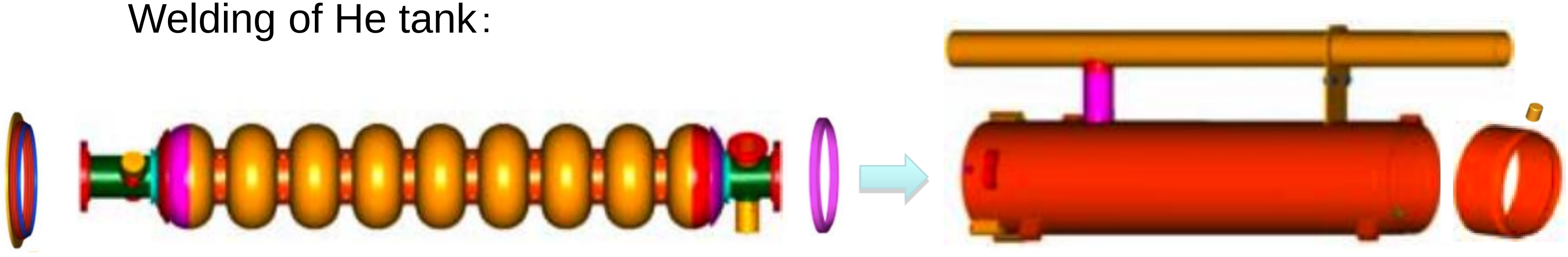
Dumbbell = EBW of two cups：

8 dumbbells are needed for one cavity

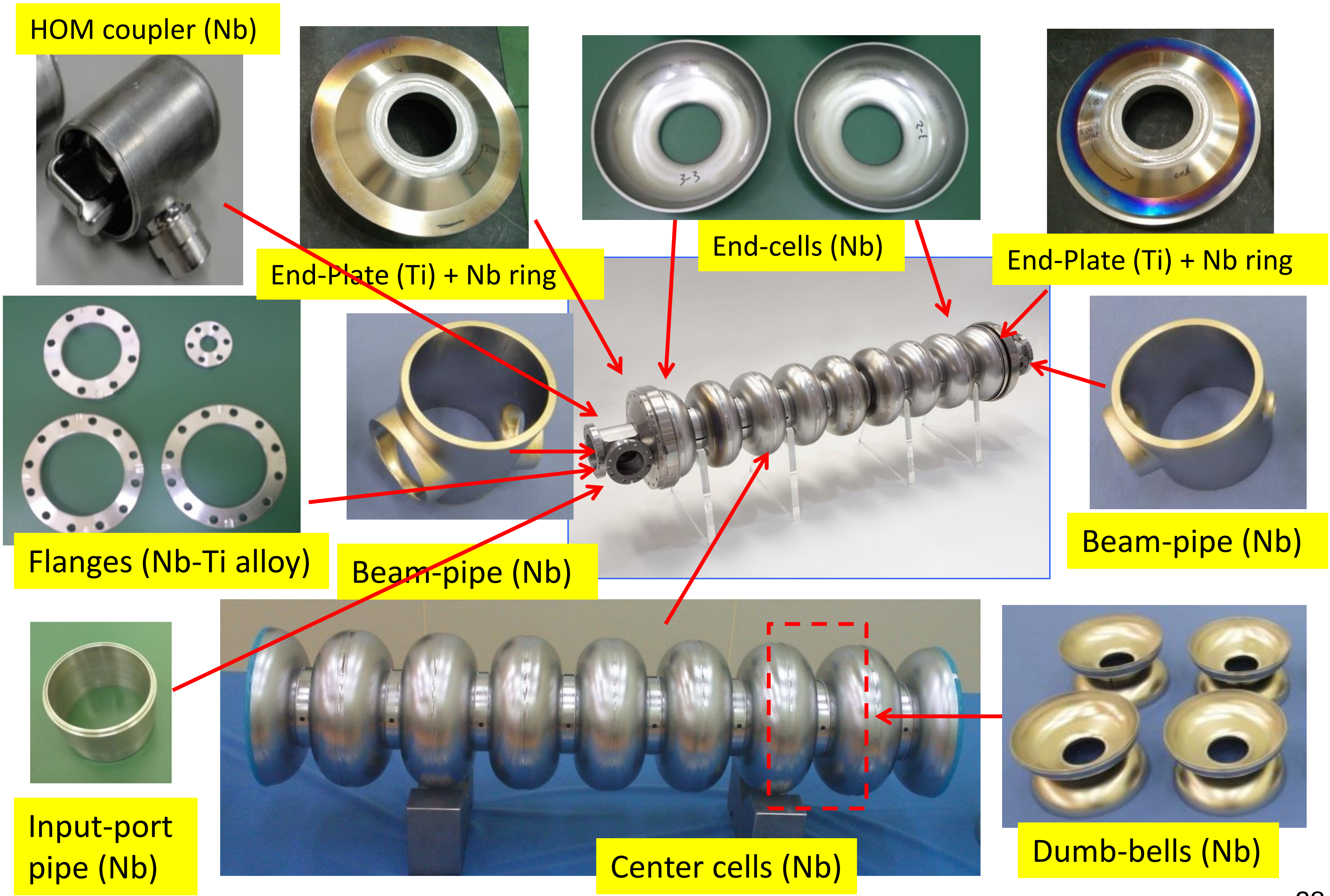
EBW assembly of all parts：



Welding of He tank：



Fabrication of 9-cell Cavity

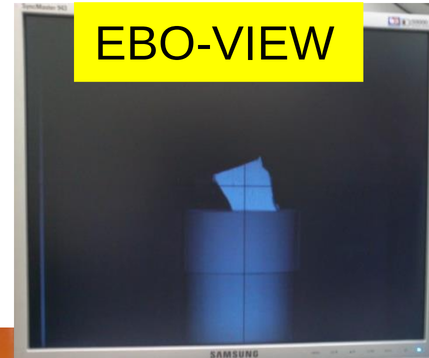


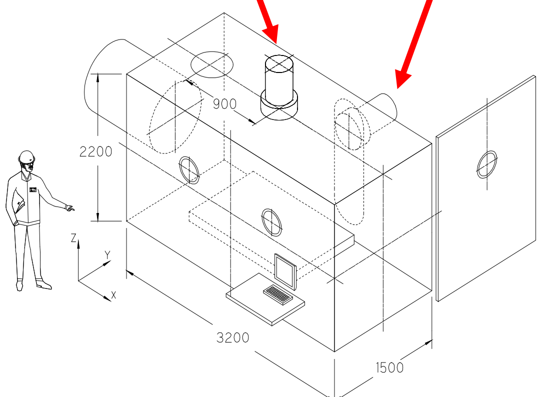
Electron Beam Welding (EBW) machine / KEK

Gun in vertical position

Gun in horizontal position

EBO-VIEW





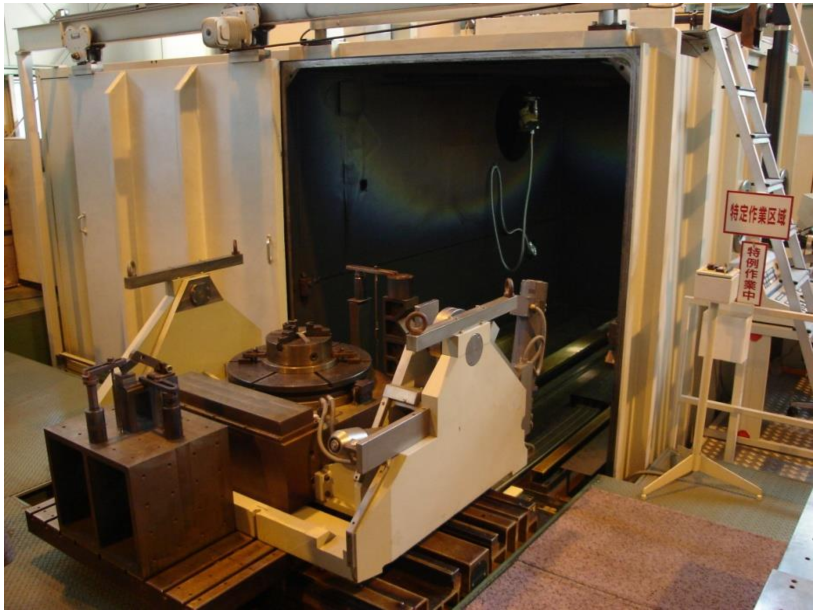
Pressure ：below 1×10^-2Pa within 20 min.
Inside material：SUS316L, Volume：10.56 m³

Steigerwald Strahl Technik

EBW machine : 150 kV, 15kW

Electron Beam Welding (EBW) Machine

Assembly of all Nb parts are done by EBW machine. This is because contamination of O2, N2, CO2, etc. degrade the SC performance of cavity.

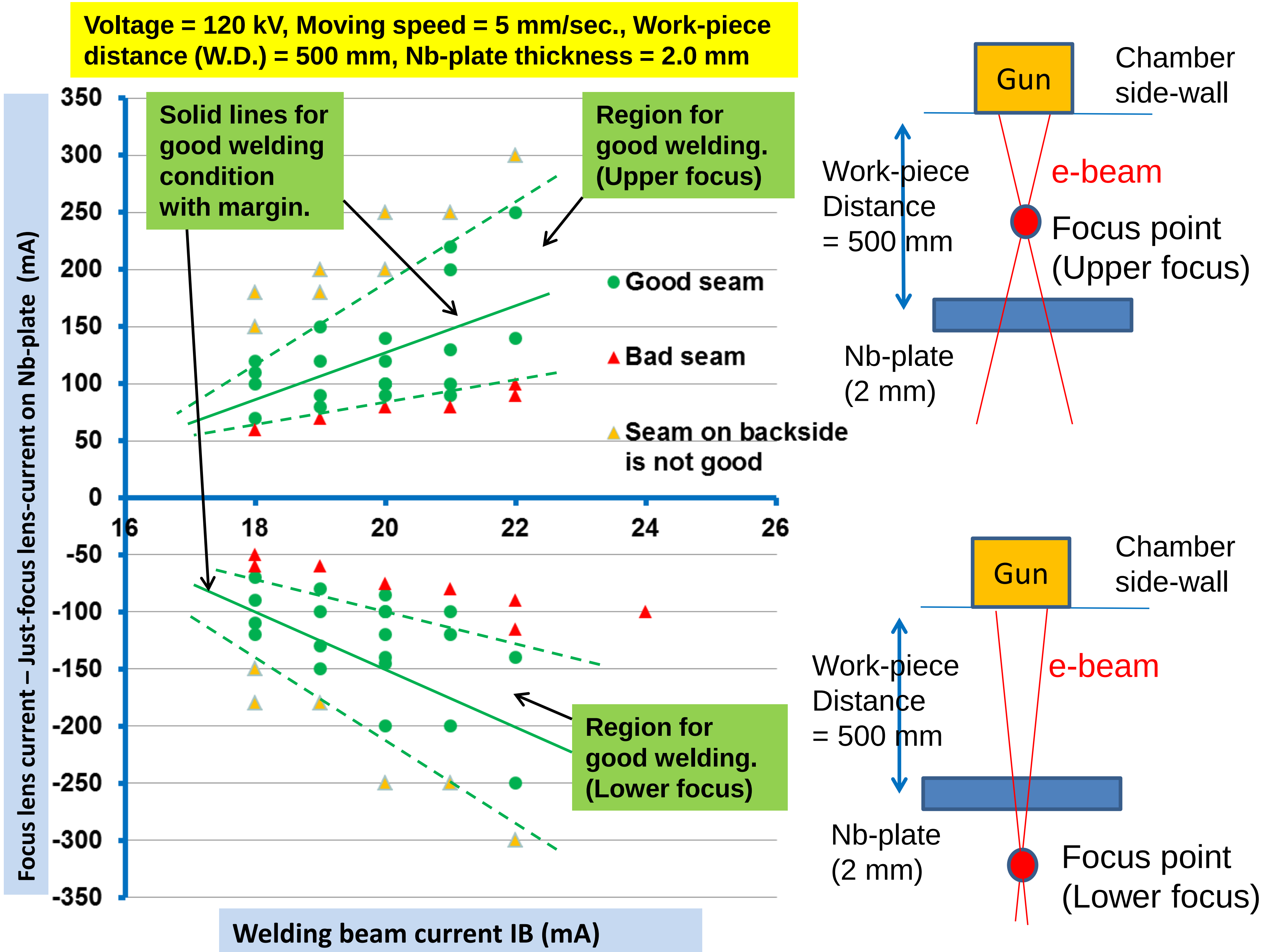


The chamber inside is pumped down to exclude the air before the EBW assembly.

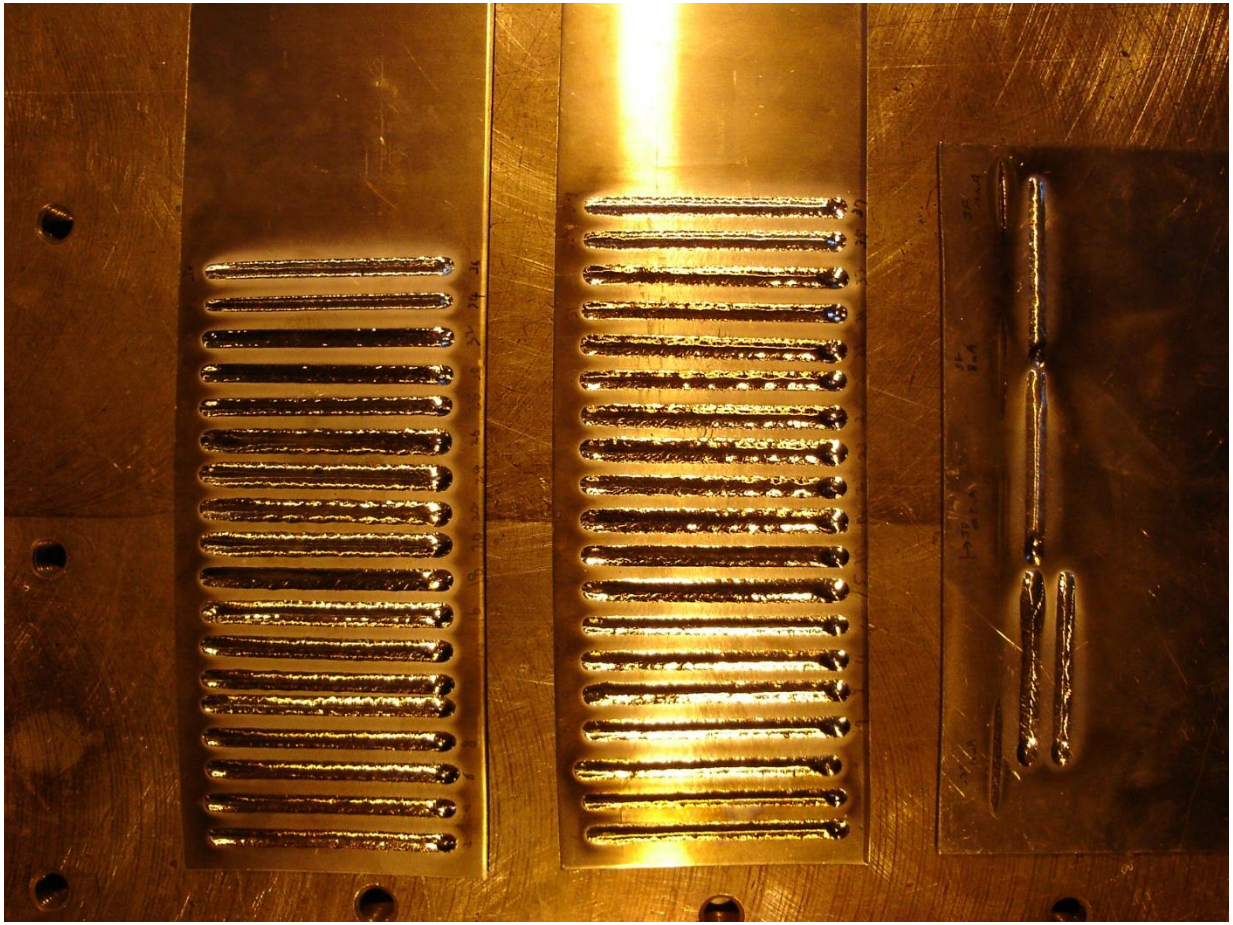
Electron Beam Welding (EBW) Machine

Electron Gun

Operator


Voltage = 120 kV, Moving speed = 5 mm/sec., Work-piece distance (W.D.) = 500 mm, Nb-plate thickness = 2.0 mm
Solid lines for good welding condition with margin.
Region for good welding. (Upper focus)
Good seam
Bad seam
Seam on backside is not good
Region for good welding. (Lower focus)
Focus lens current – Just-focus lens-current on Nb-plate (mA)
Welding beam current IB (mA)
350
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
16
18
20
22
24
26
Gun
Chamber side-wall
Work-piece Distance = 500 mm
e-beam
Focus point (Upper focus)
Nb-plate (2 mm)
Gun
Chamber side-wall
Work-piece Distance = 500 mm
e-beam
Nb-plate (2 mm)
Focus point (Lower focus)

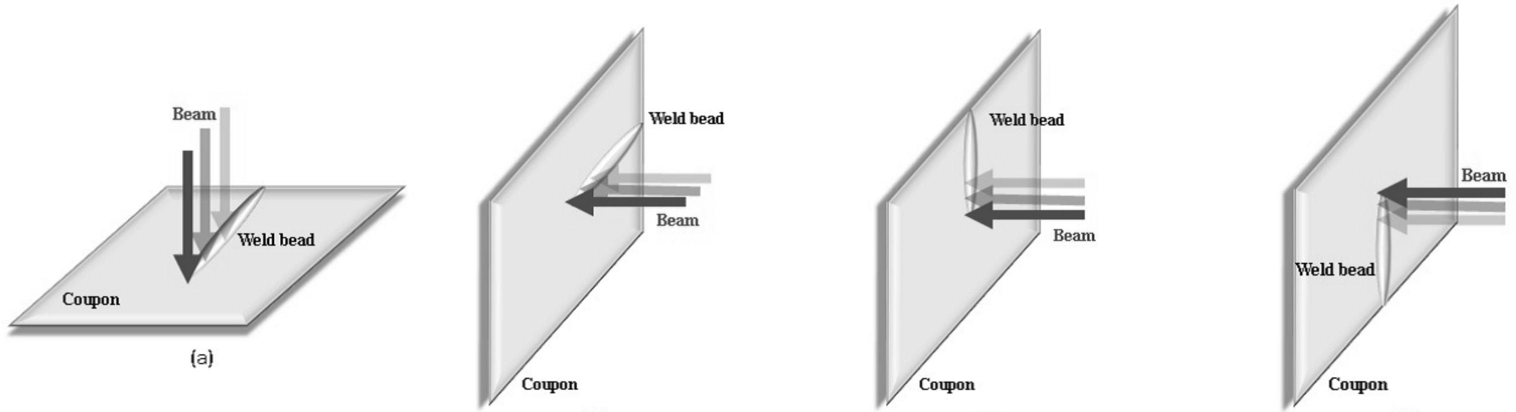
Electron Beam Welding (EBW) parameter search



Beam-parameter search with Nb test-pieces.
Oscillation of beam was applied.

Studies on EBW parameter

Search for good EBW parameter was done by changing the welding beam-voltage, beam-current, focus-current, working-piece distance from gun, working-piece moving speed, Nb-plate thickness, and the gun and working-piece configuration.

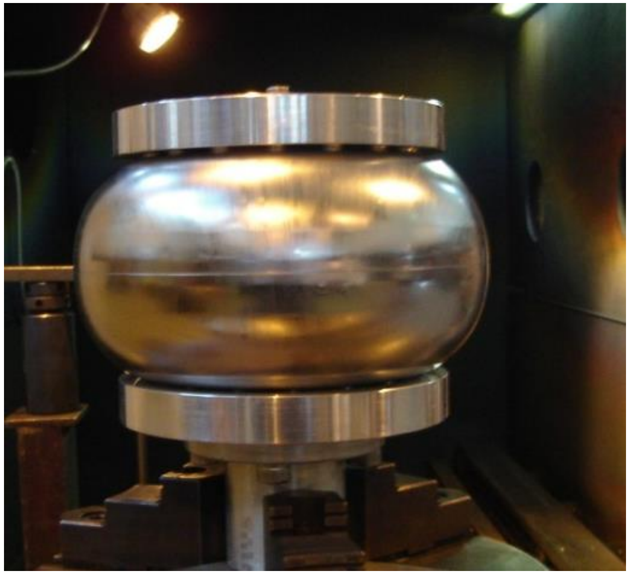


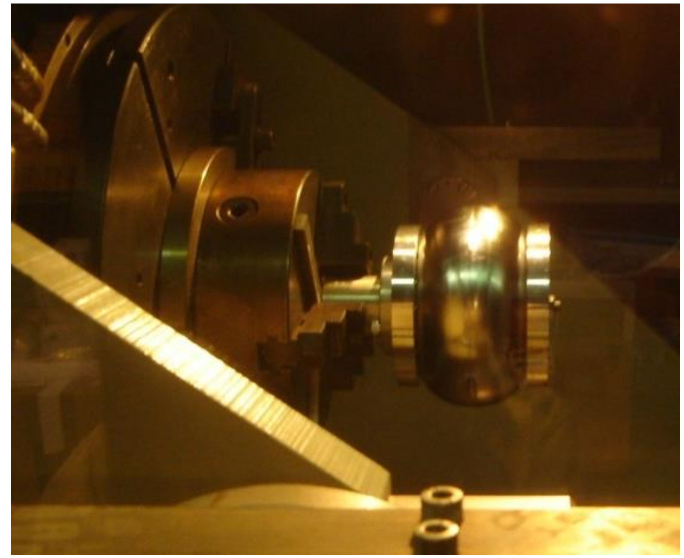
Vertical beam	Horizontal beam (See next slide)	Horizontal beam Downward welding	Horizontal beam Upward welding

In particular, the gun and working-piece configuration affects the results of welding seam.

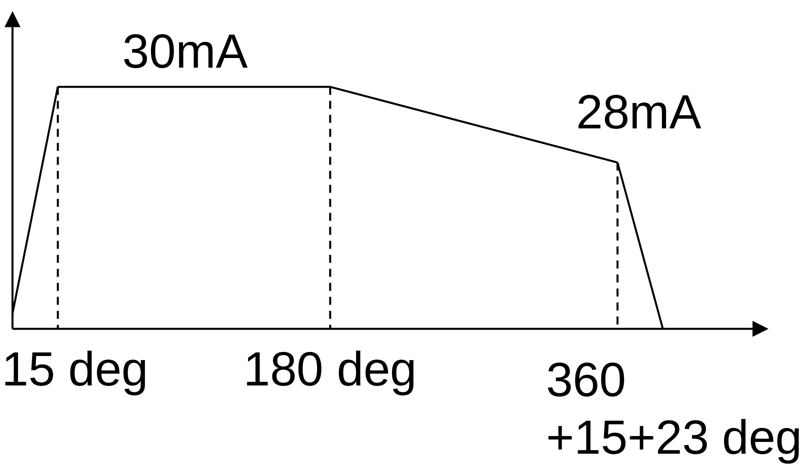
For more details of studies on EBW parameters , see following presentation.
ID: 3364 - WEPWO015 / 2013 15th May (Wed.), IPAC2013 by T. Kubo (KEK):
Title: Electron Beam Welding Parameters for High Gradient Superconducting Cavity

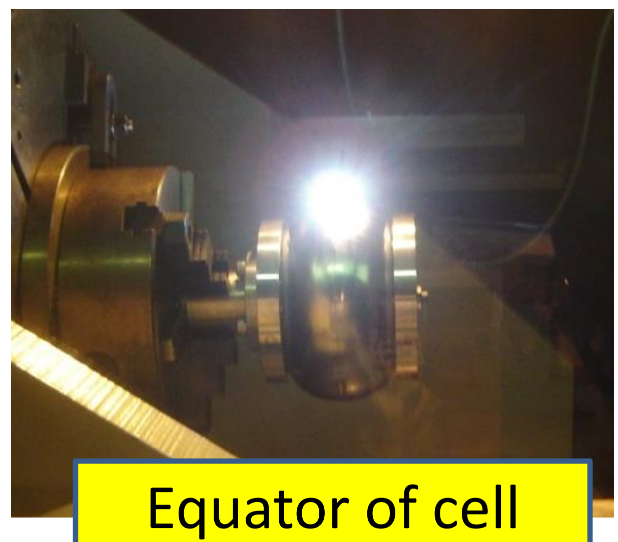
Electron Beam Welding (EBW) parameter search



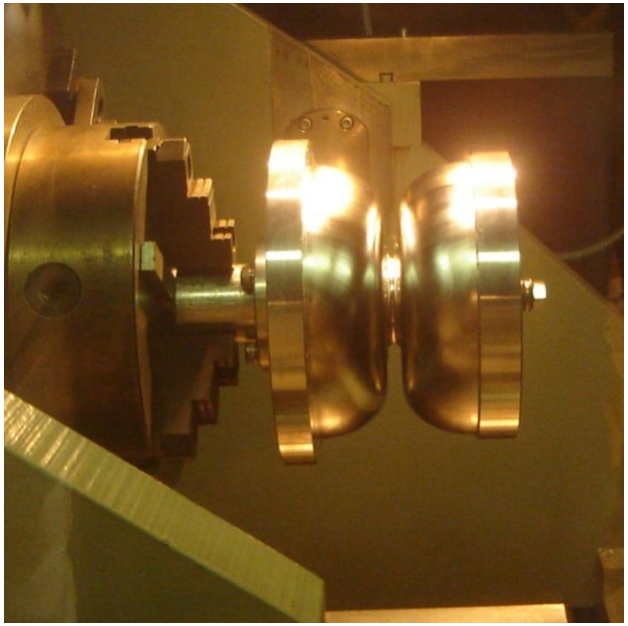


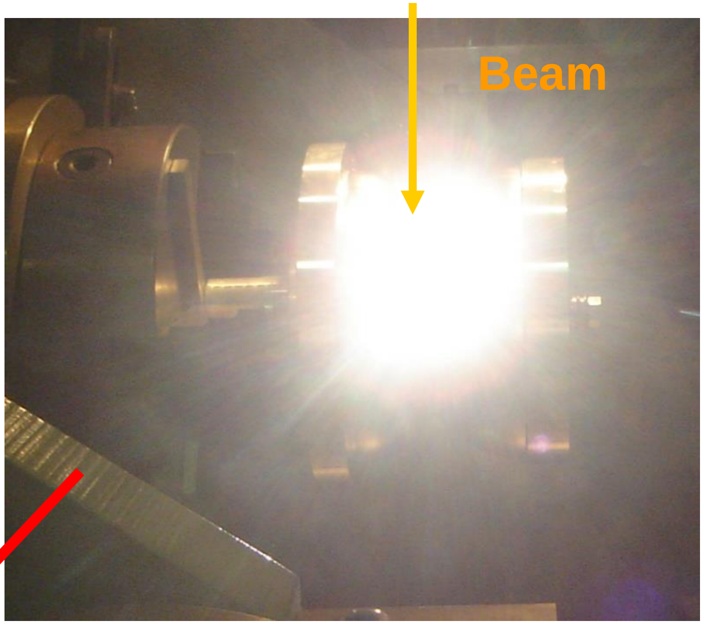
150 kV, 30 mA, 10 mm/s





EBW of Dumbbell

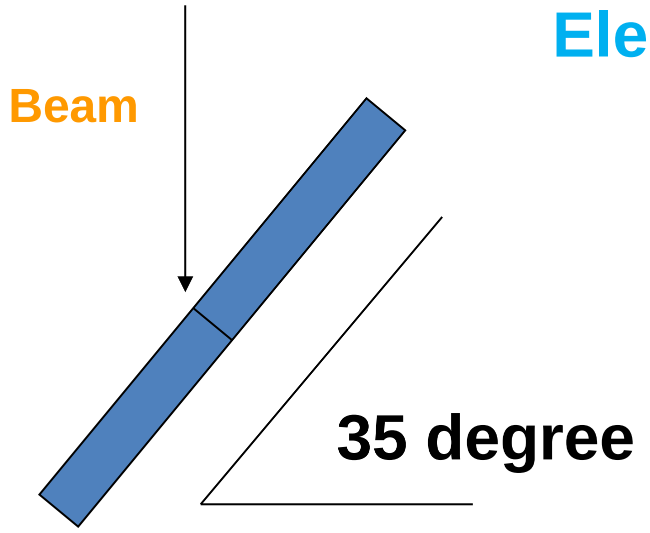


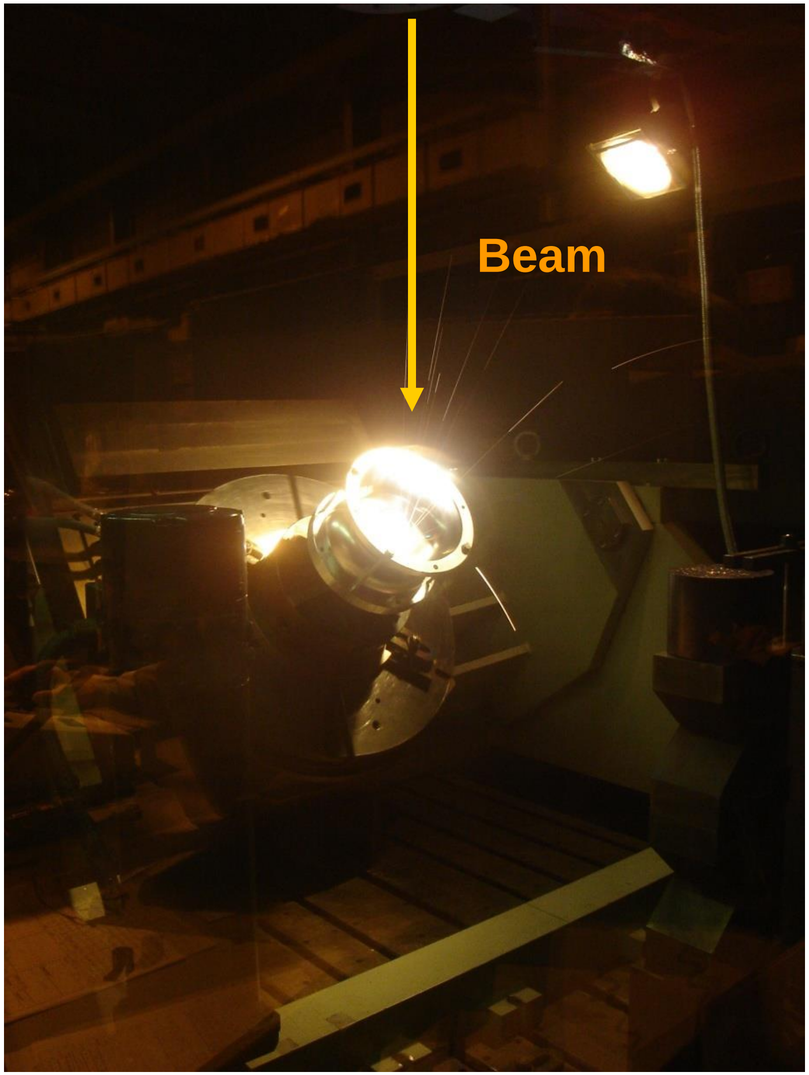


Outside, EBW depth = 70%
150kV, 18 mA, 10 mm/s

High electric field at iris.
The inner surface of iris should be smooth to avoid field-emission.

Electron Beam Welding (EBW)



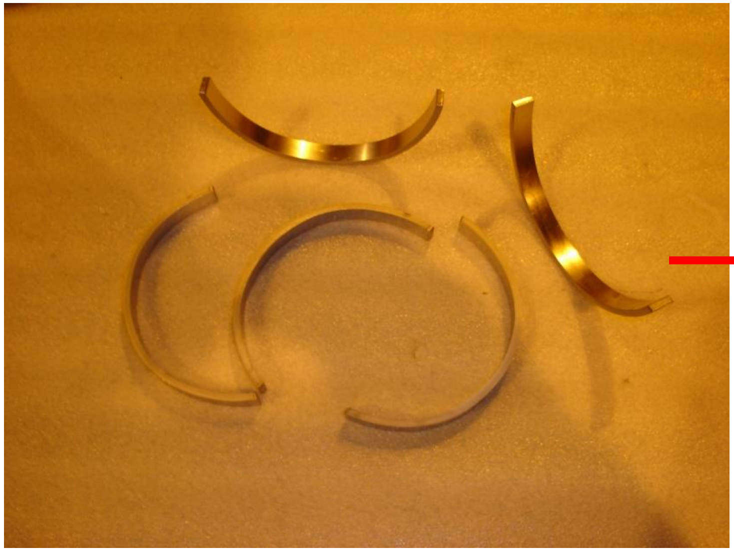


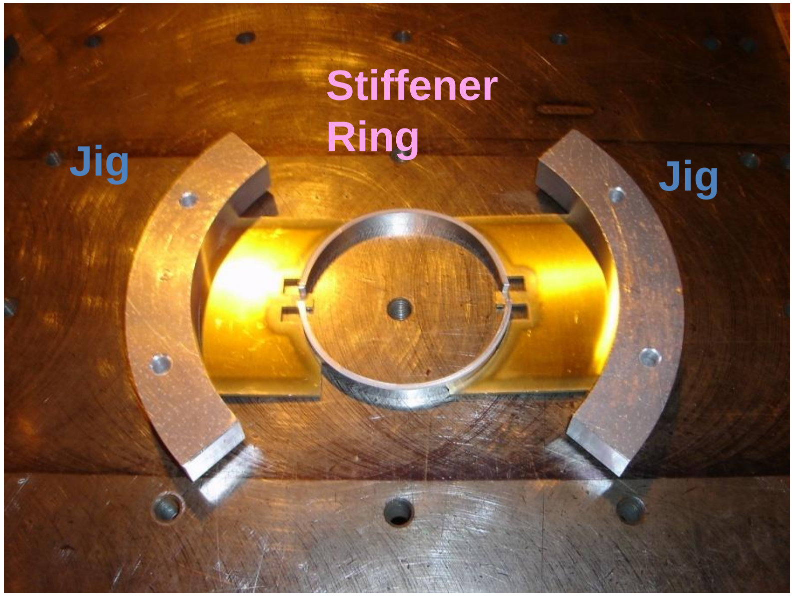
Inside, EBW depth = 40% (10% overlap)

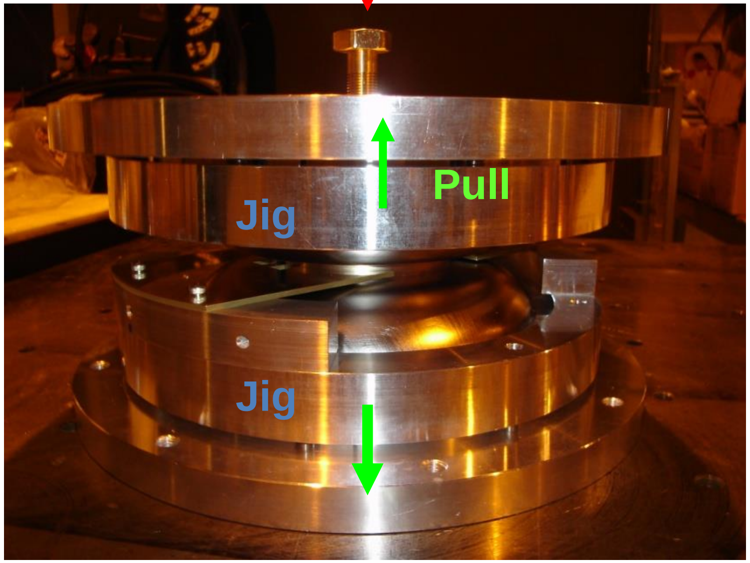
150kV, 10mA, 10 mm/s

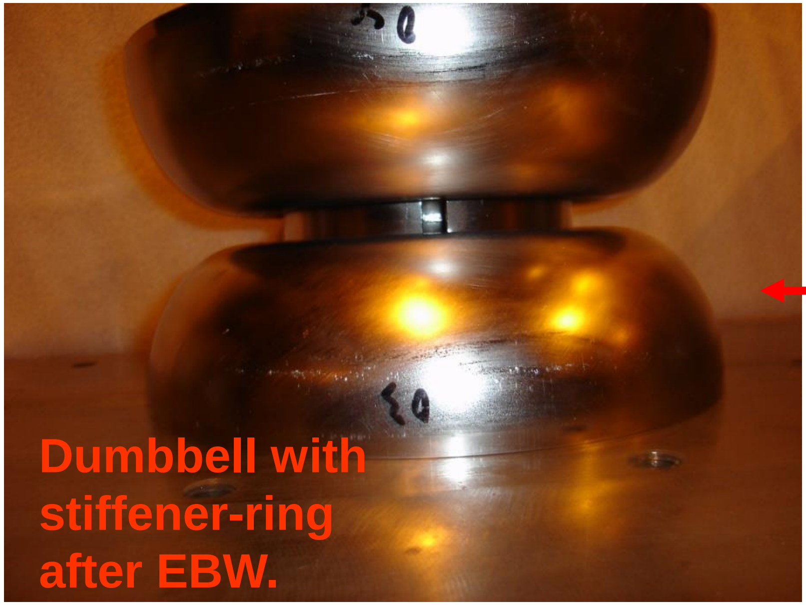
Cooling 5 min. => 45 C

Stiffener-ring





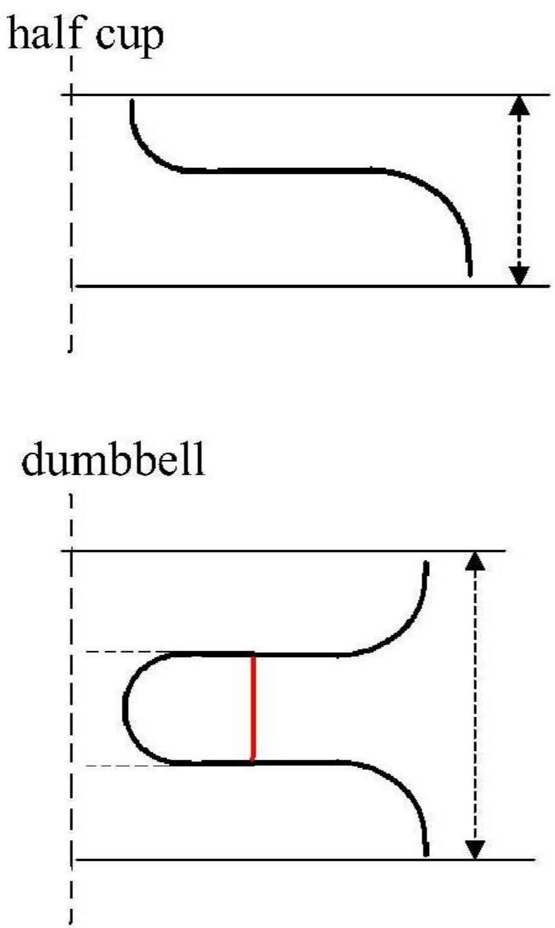




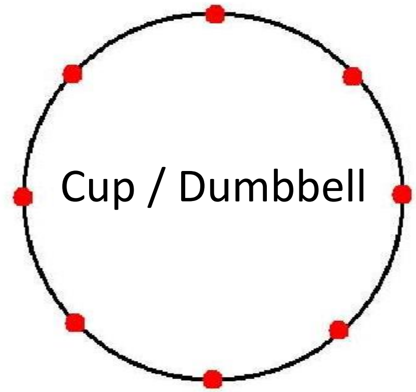
3-Dimensional Measurement

3-Dimensional Measurements of cup and dumbbell

Height measurement

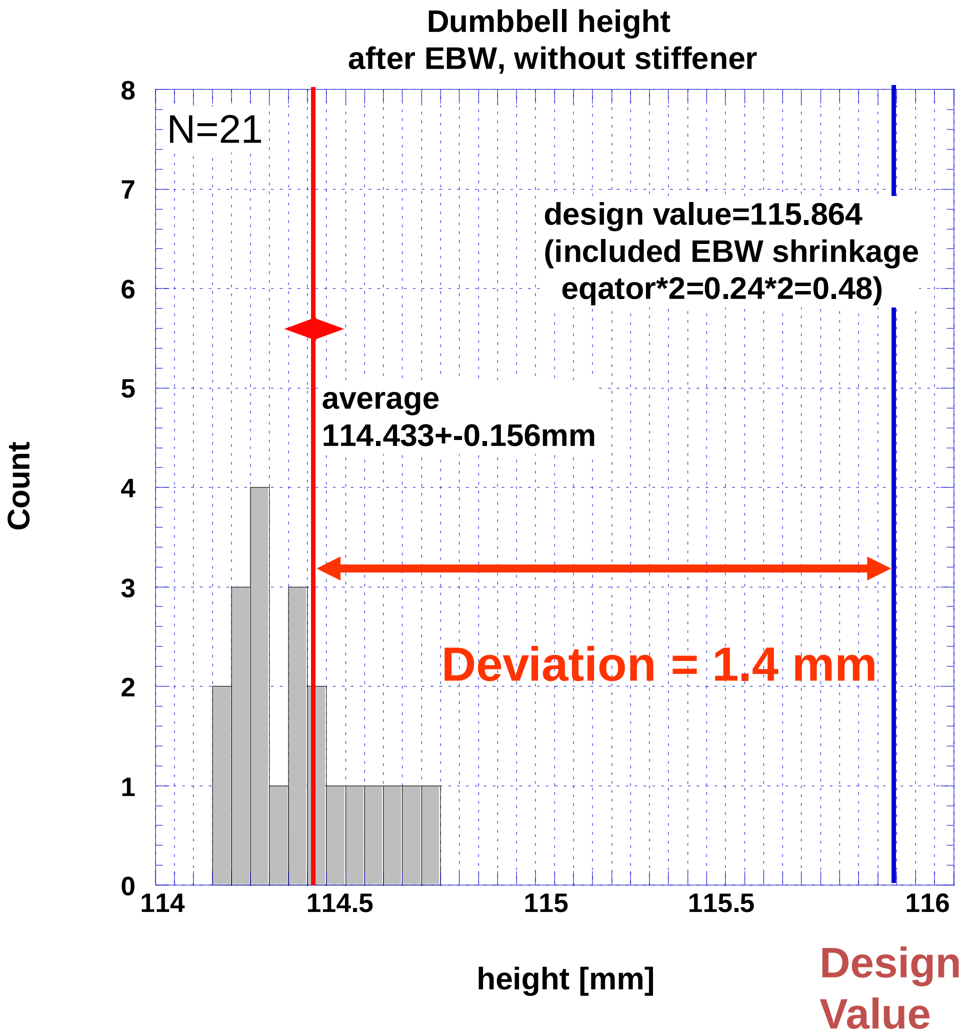


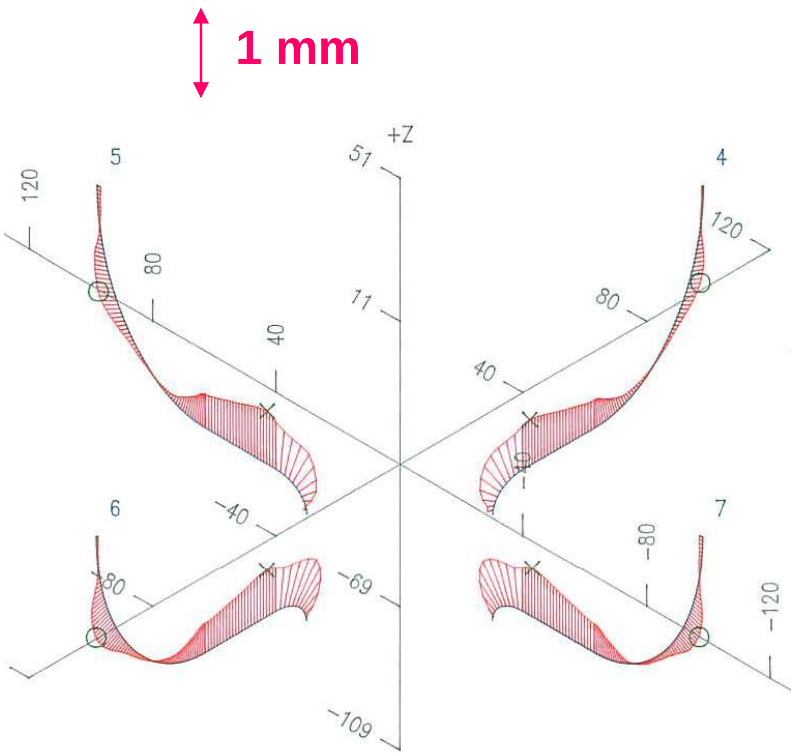
measured by 8 points



measured by KEK Mechanical Engineering Center

Dumbbell-height measurement and tuning

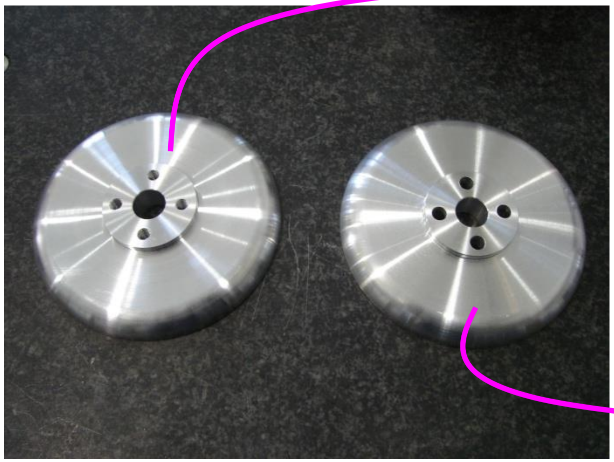


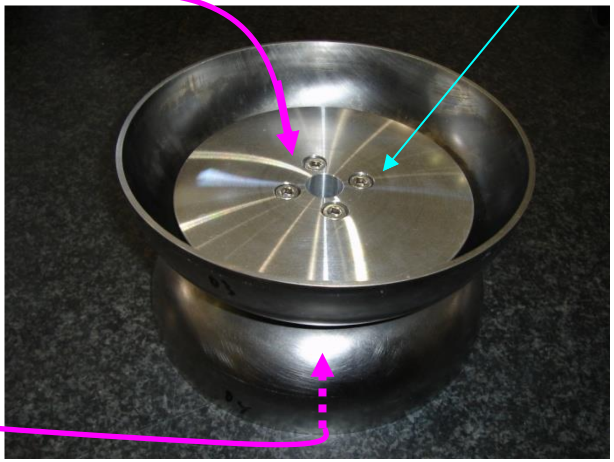


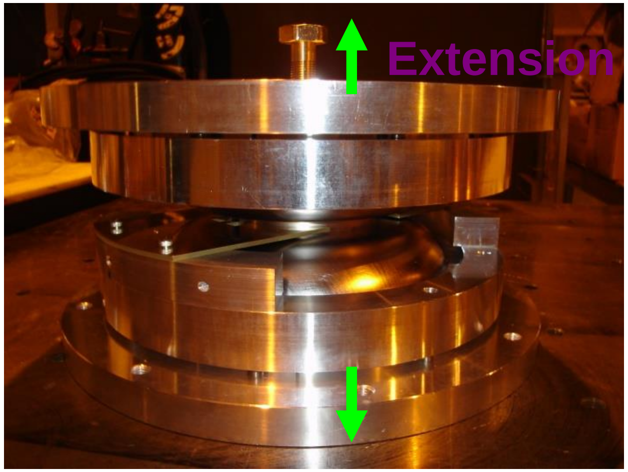
3-D measurement of dumbbell before tuning

Tried to extend each dumbbells by ~1 mm.

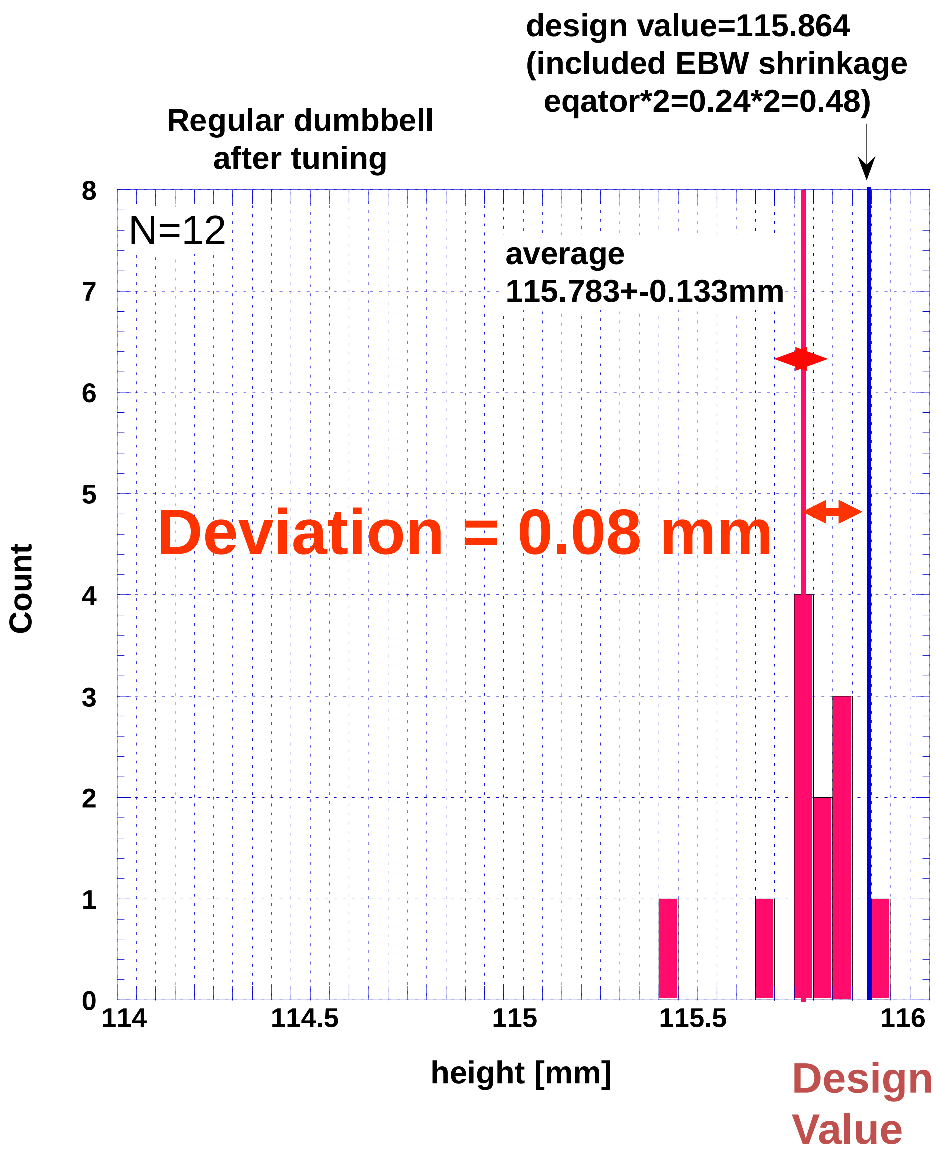
Fix two plates by bolts.

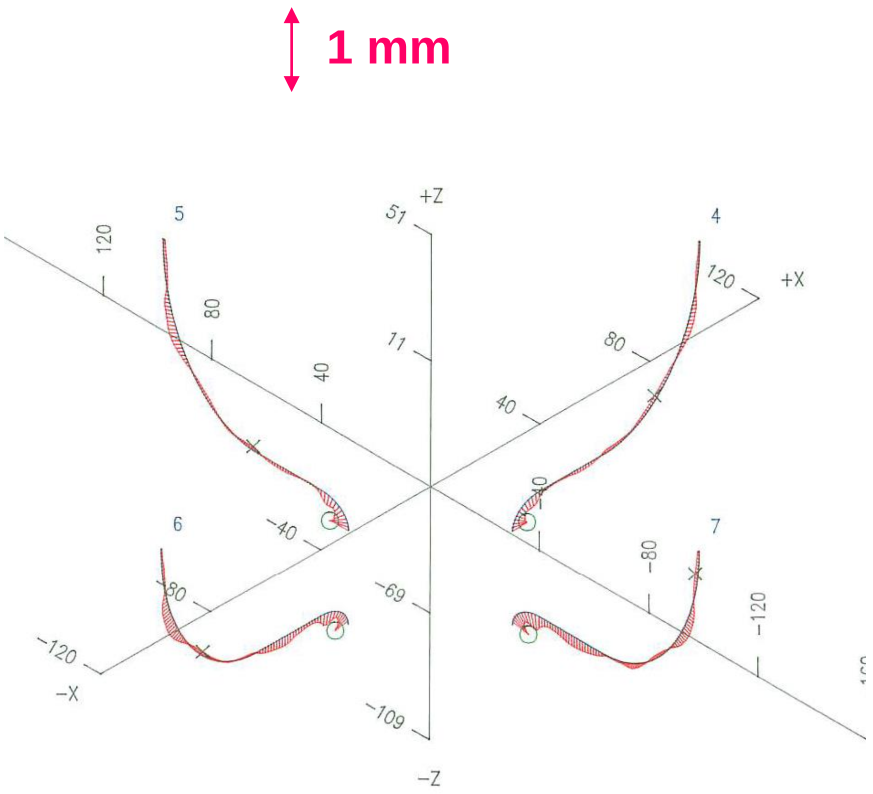






Dumbbell-height measurement and tuning

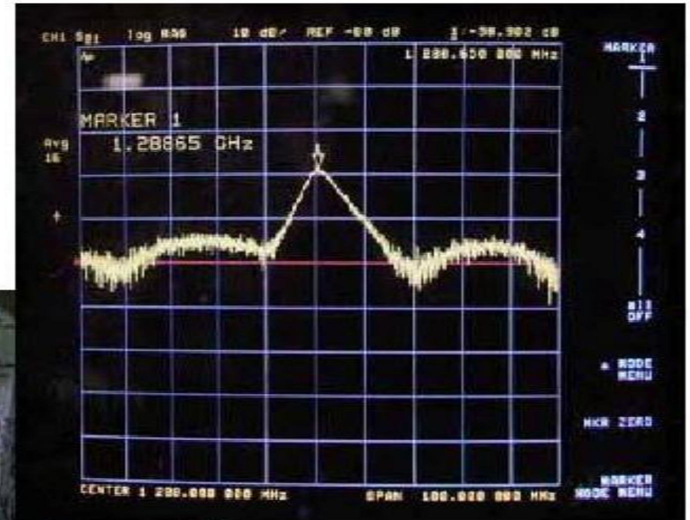


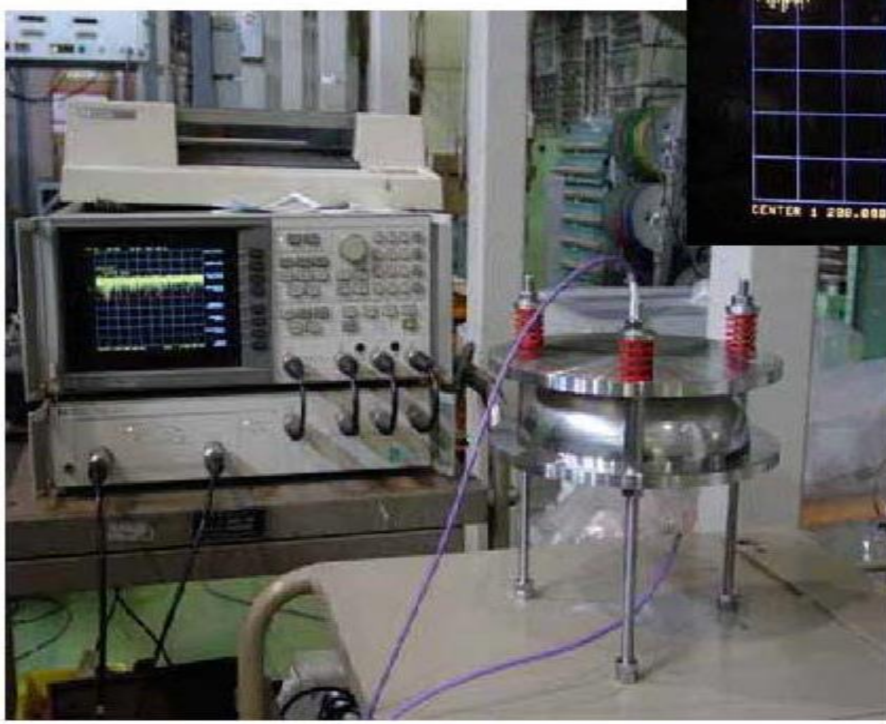


3-D measurement of
dumbbell after tuning

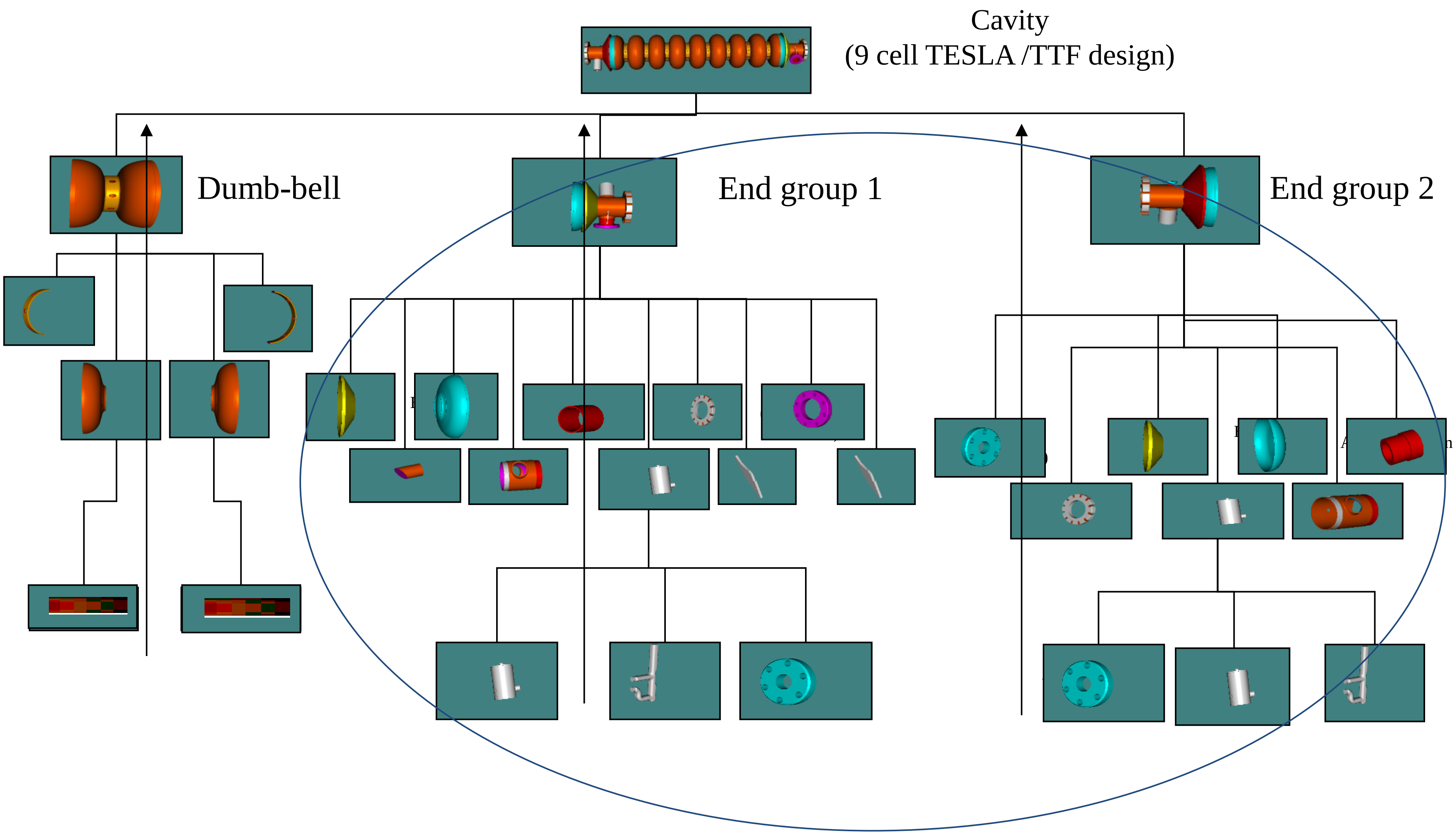
Frequency measurement of cup / dumbbell

Frequency measurement

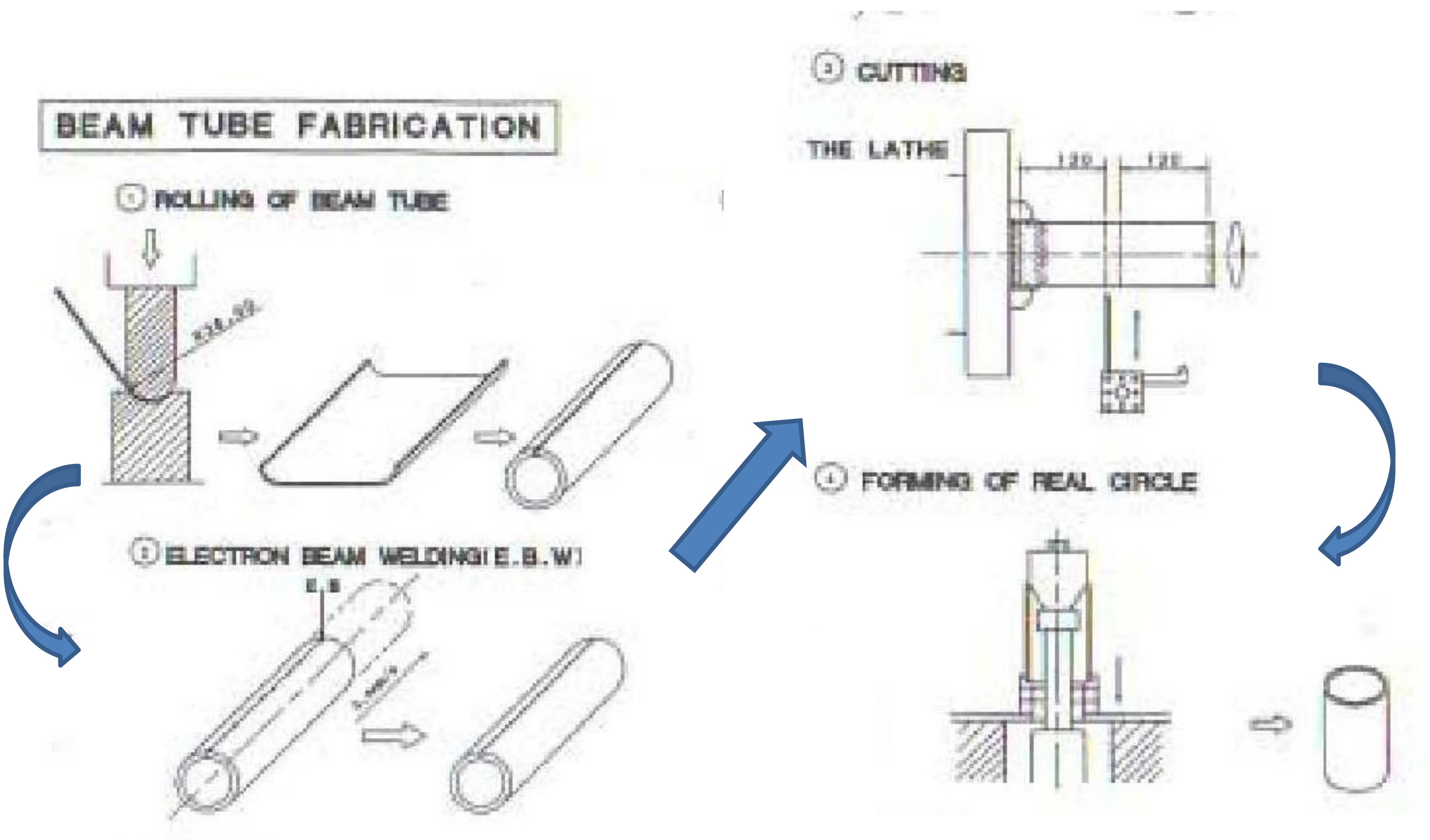




Overview over Fabrication of 9-cell cavity

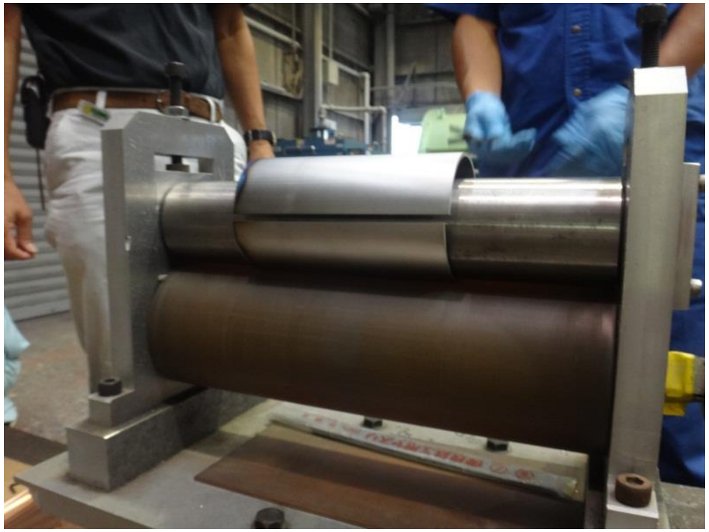


Fabrication Processes of beam-pipe



Rounding of Beam Pipe from Nb plate

Rounding of Beam Pipe from Nb plate

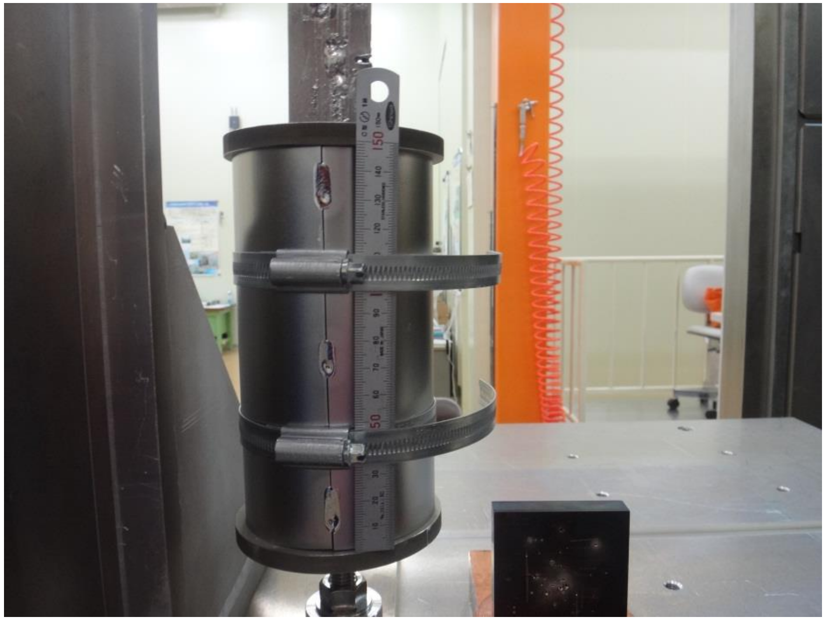


Final rounding

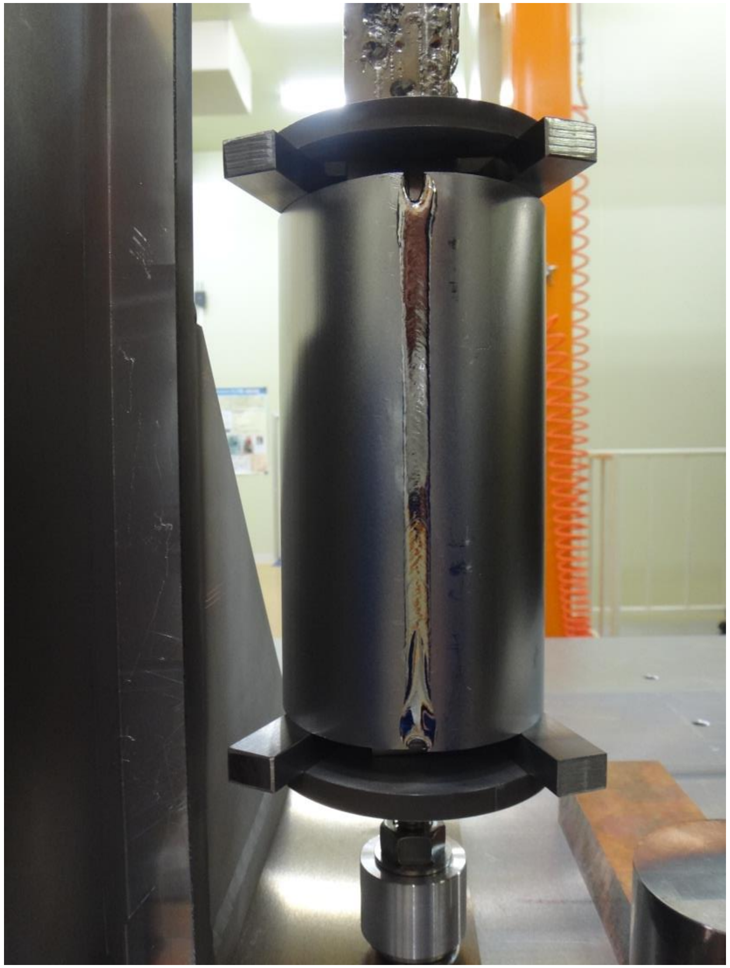
After rounding

Fixture for EBW

EBW of Beam Pipe

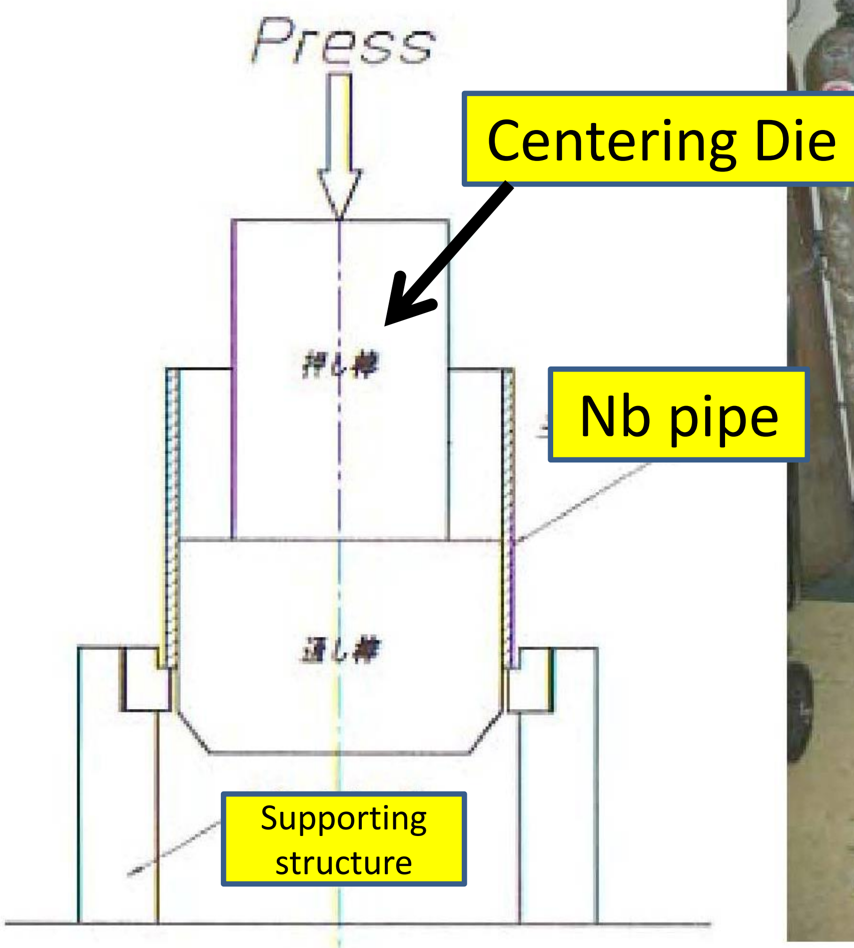


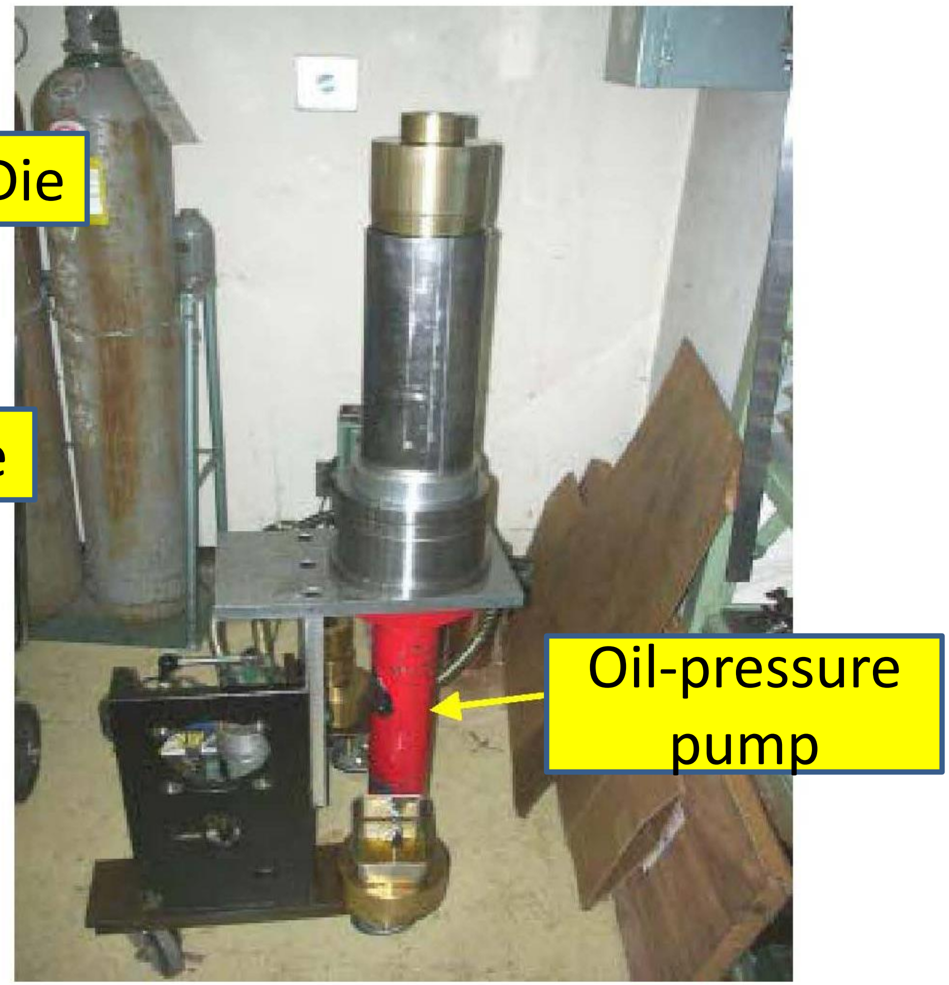
Point EBW



After EBW

Centering of Beam Pipe





Fabrication Processes of beam-pipe

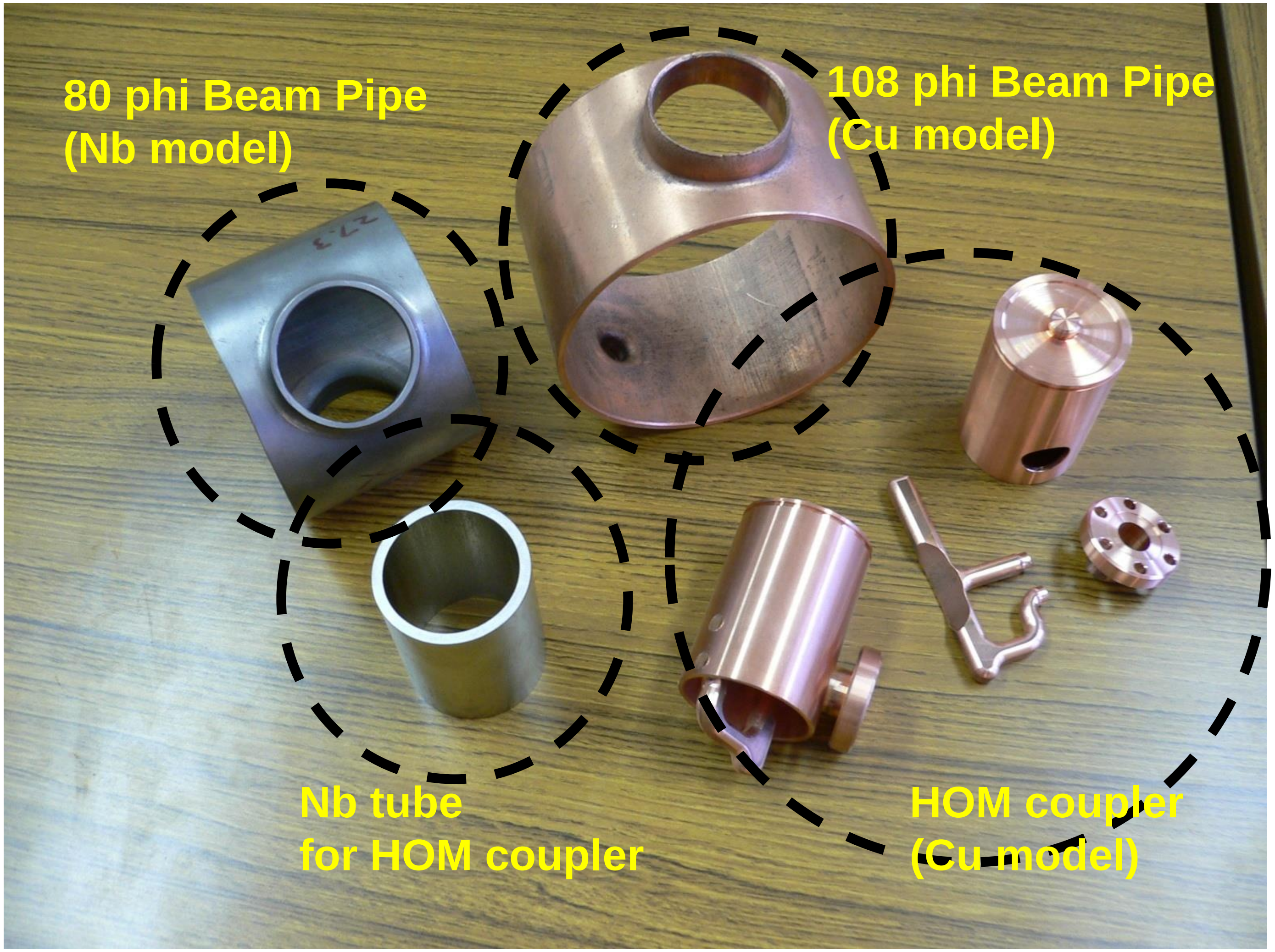
- The fabrication methods of beam-pipe are depending on the industries.
- Deep-drawing from a Nb plate to a pipe: For this process, several deep-drawing processes with different dies are needed with annealing process inbetween deep-drawing processes.
- Back-extrusion from a shaped Nb ingot to a pipe: Fabrication of Nb plate is skipped in this process, but you need a large press machine.

Beam Pipe

80 phi Nb Beam-pipe (input-coupler)

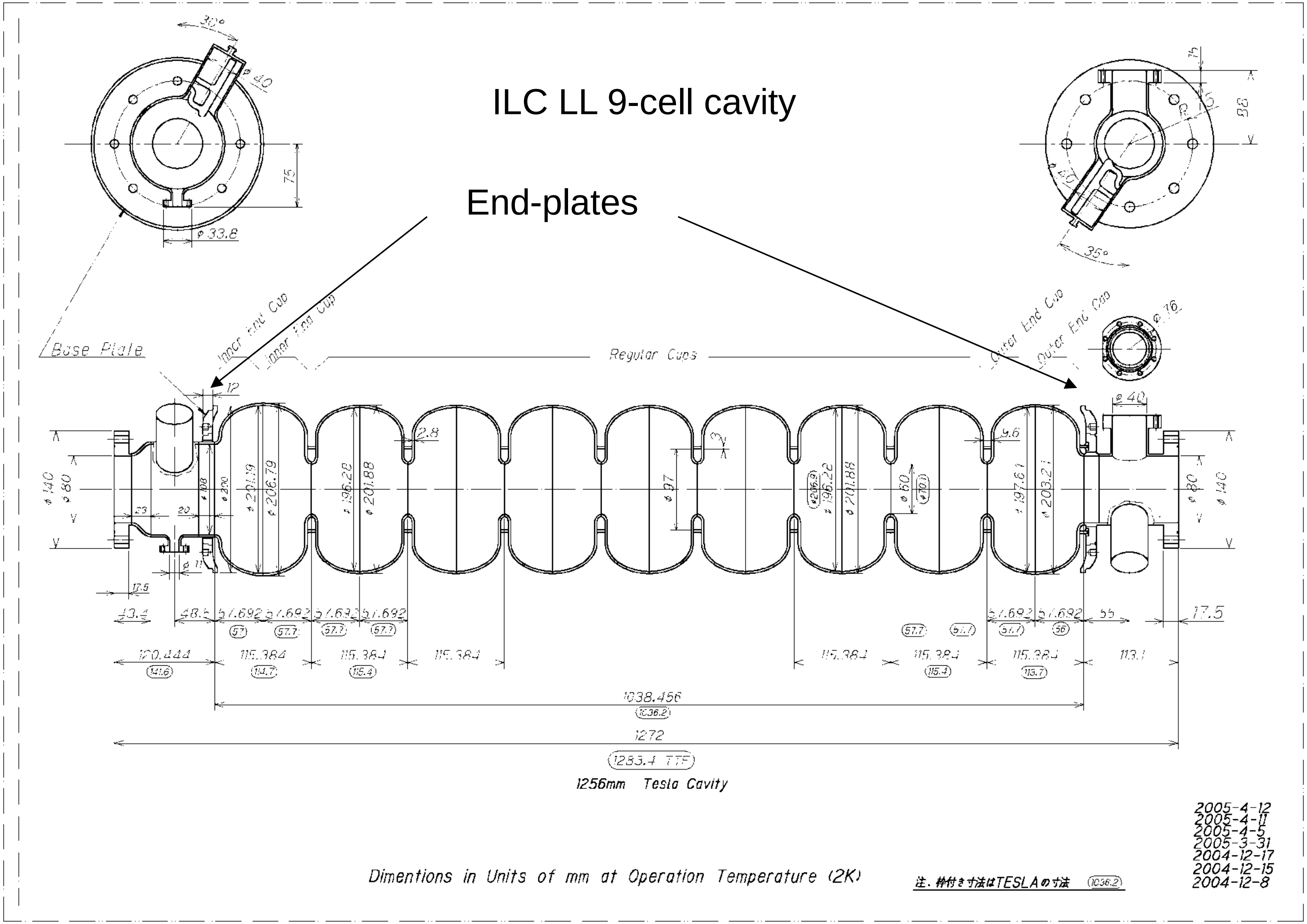
108 phi Nb Beam-pipe (pickup)

End-group

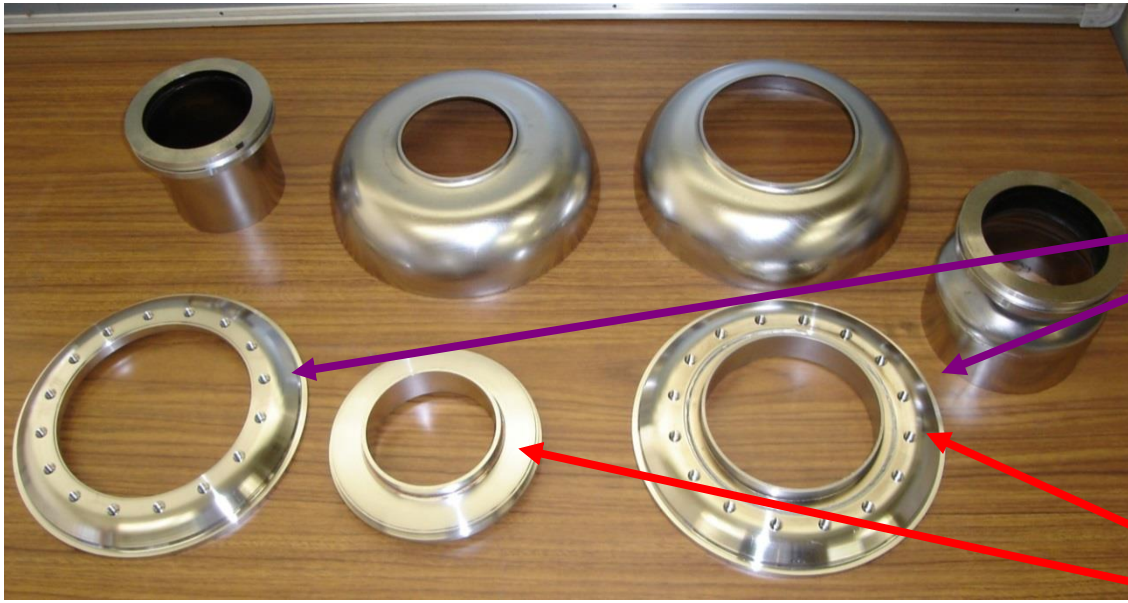

80 phi Beam Pipe
(Nb model)
108 phi Beam Pipe
(Cu model)
Nb tube
for HOM coupler
HOM coupler
(Cu model)

End-group

End-plates / joint to He jacket

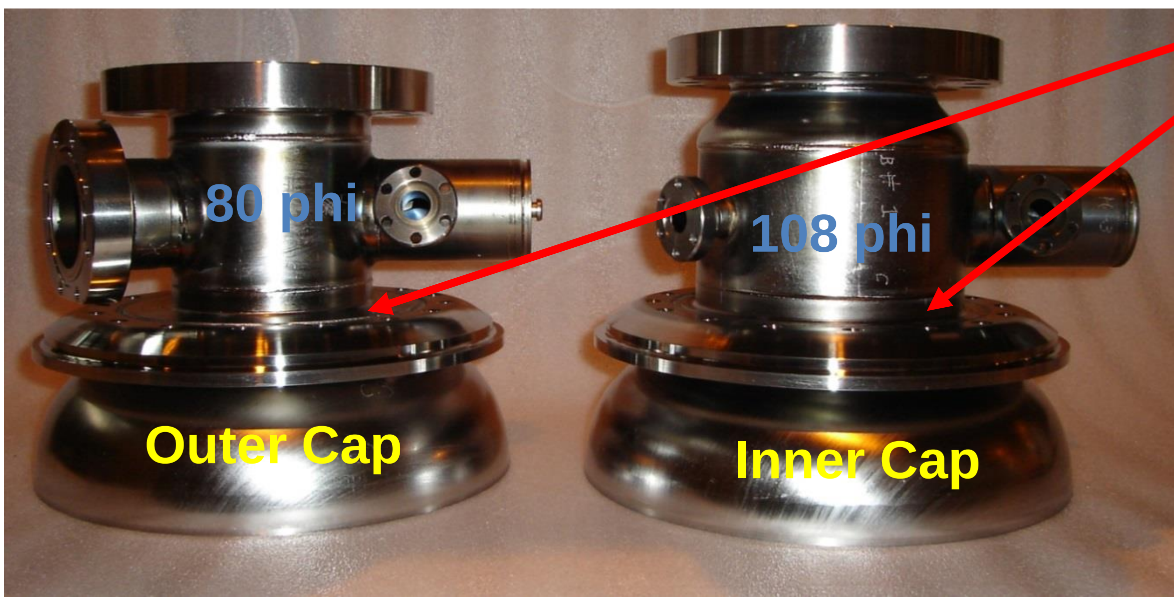


End-plates / joint to He jacket

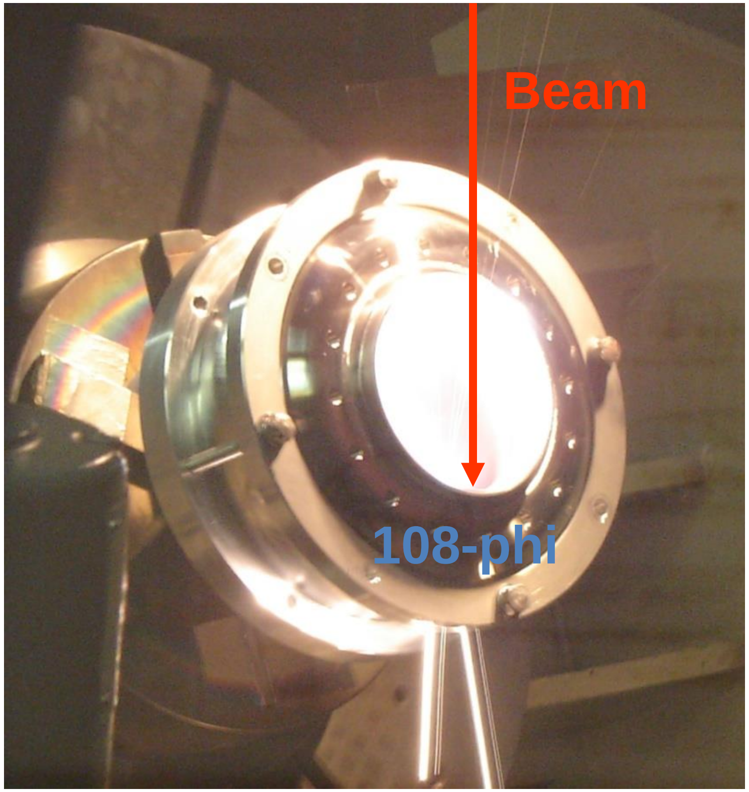


SUS Base-plate

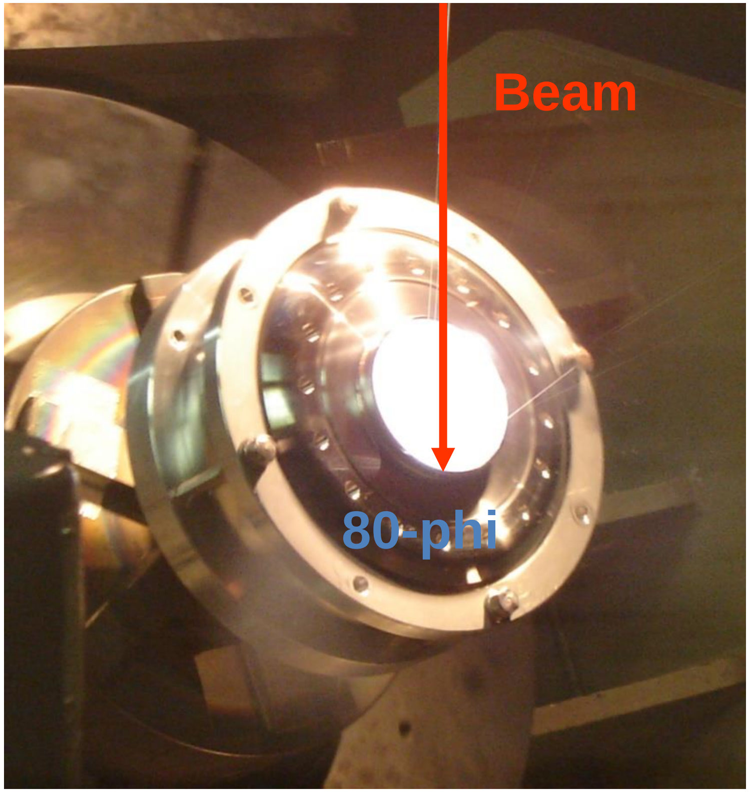
HIP bonding



End-group EBW

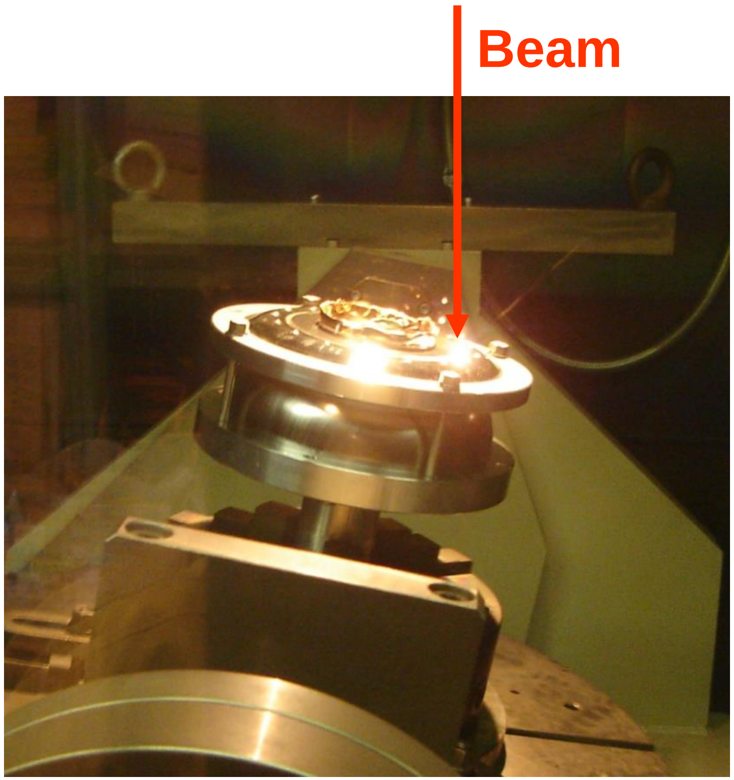


Base-plate 108-phi beam-pipe
+ Inner End-Cap

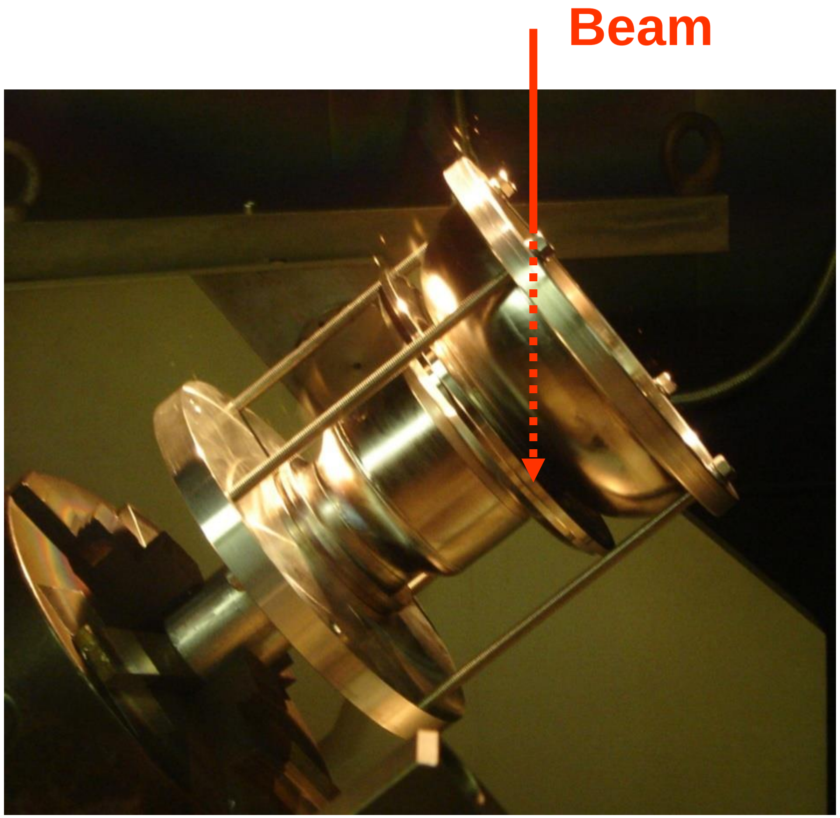


Base-plate 80-phi beam-pipe
+ Outer End-Cap

End-group EBW



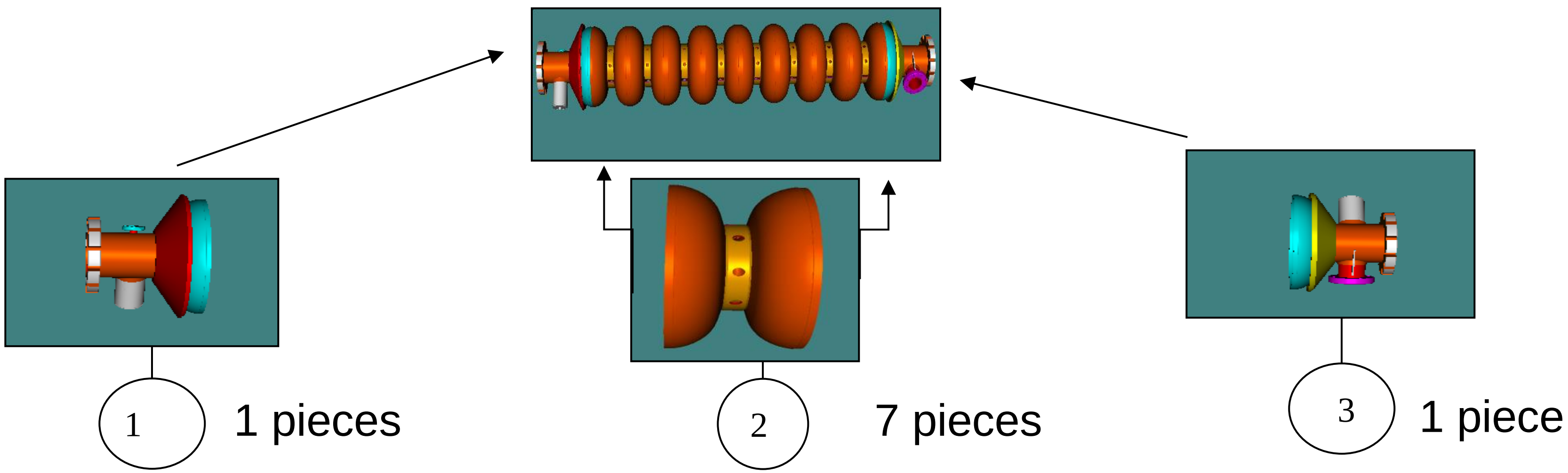
EBW of SUS Base-plate



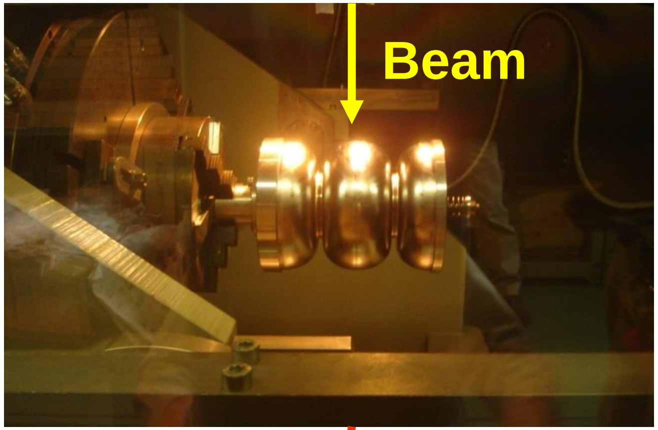
EBW of 108-phi beam-pipe

End-group assembled by EBW

EBW assembly of end-group + dummbells



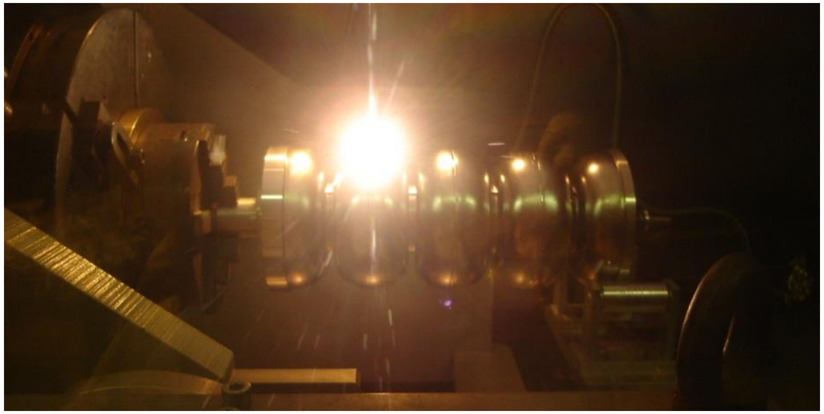
EBW of two dumbbells

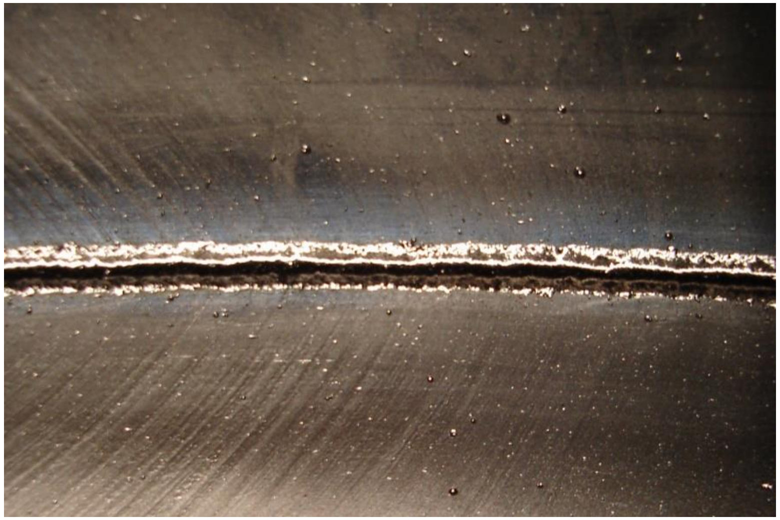


High magnetic field at equator.
The inner surface of equator should be defect-free.

Good inner surface
(EBW with beam oscillation)

EBW of four dumbbells

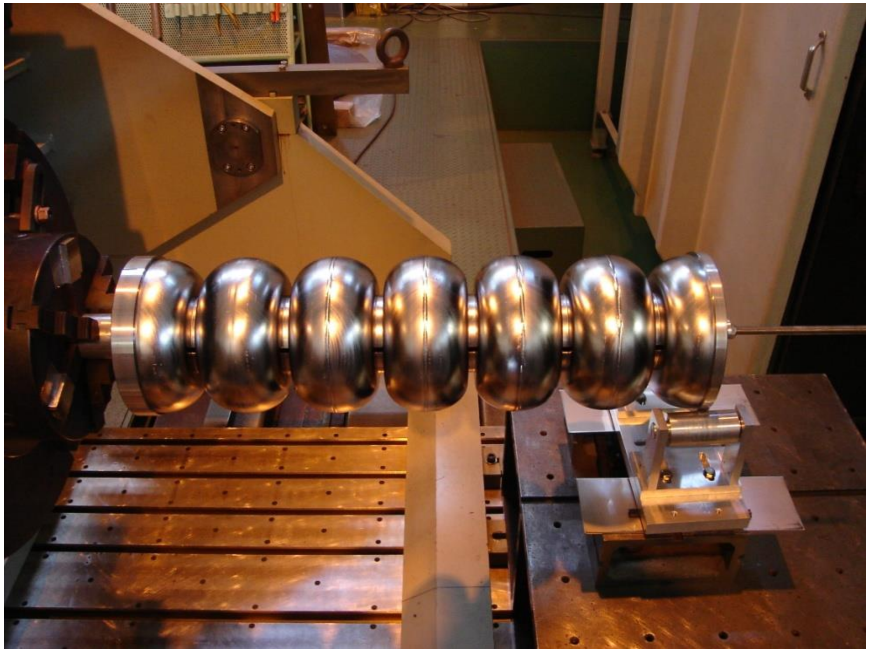




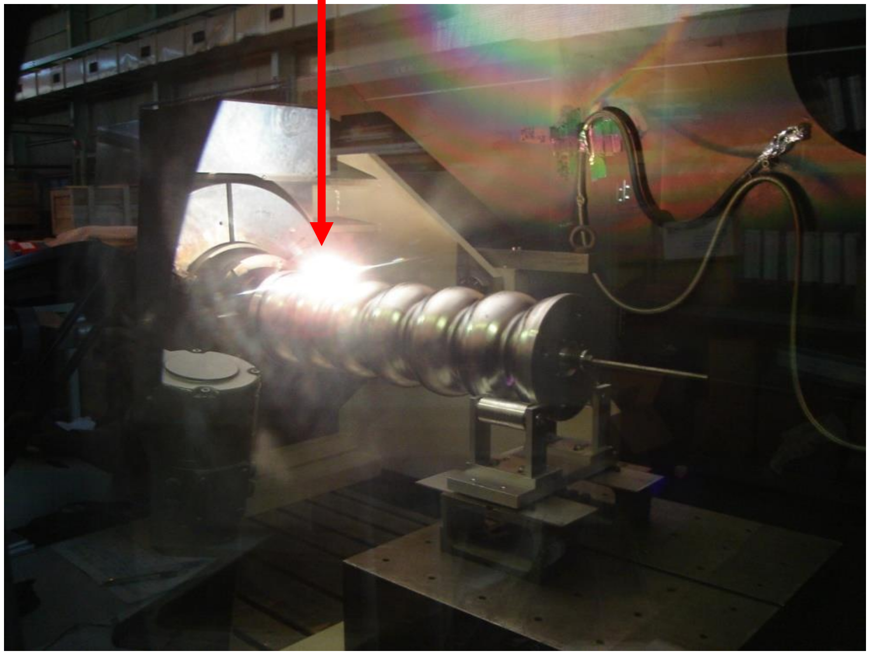
Bad EBW example

EBW of six dumbbells

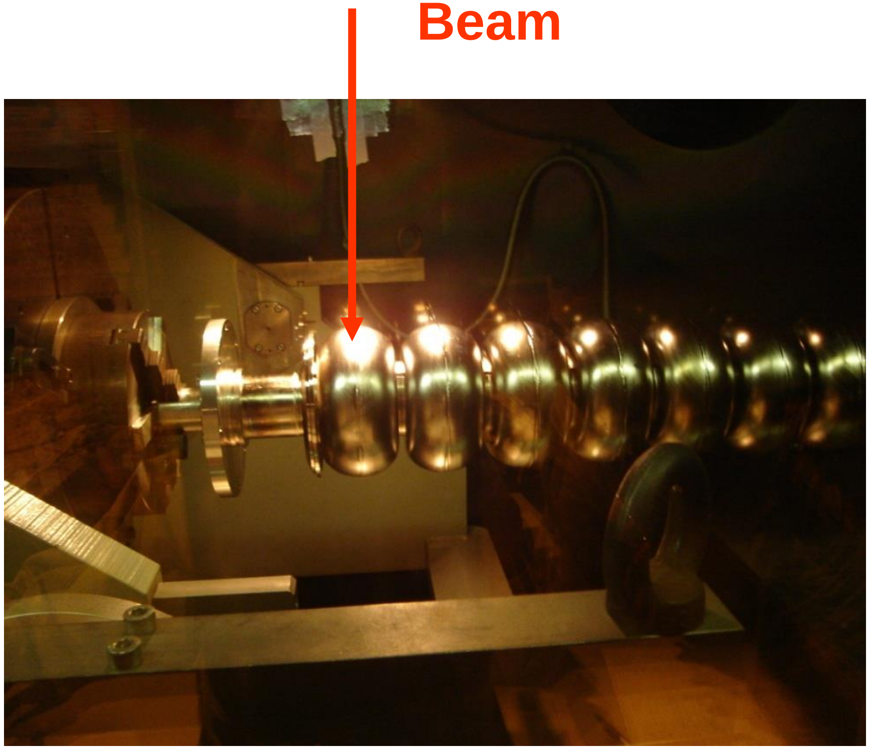
Six dumbbells



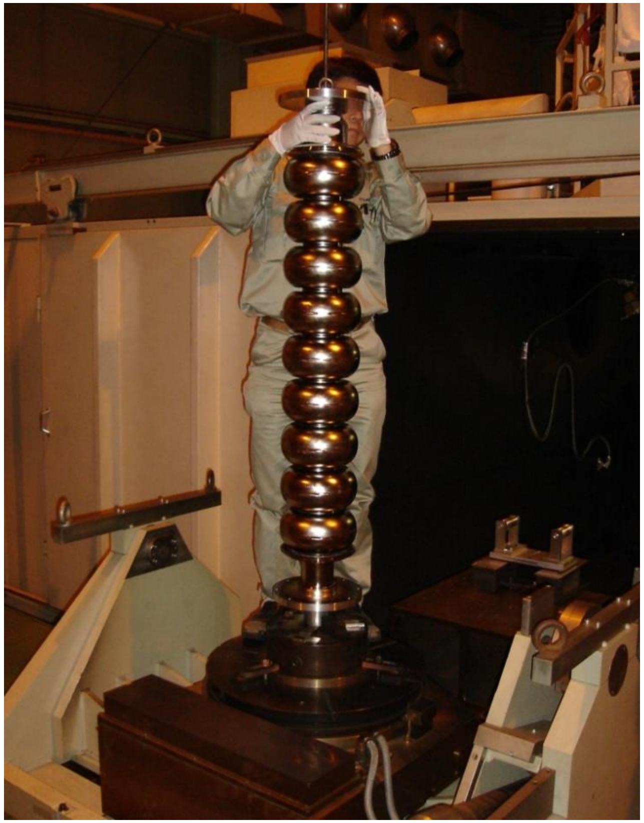
Beam



EBW of Center-cells + End-group



EBW of End-group + Center-cells

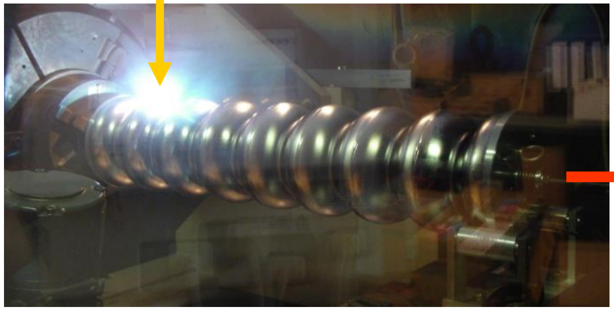


EBW completed

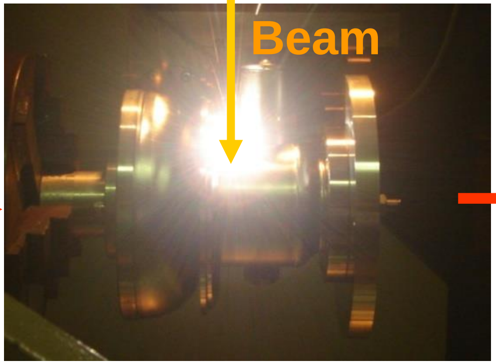
Fabrication of LL Cavity at KEK

EBW of dumbbells

Beam



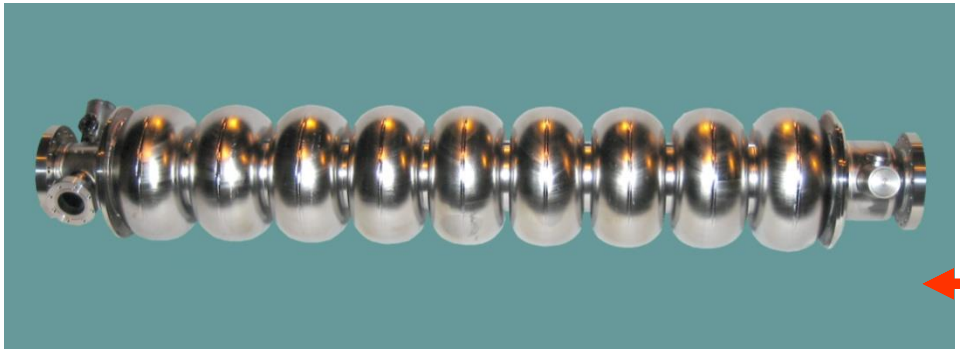
EBW of end-beam-pipe



End-beam-pipes with HOM and flanges

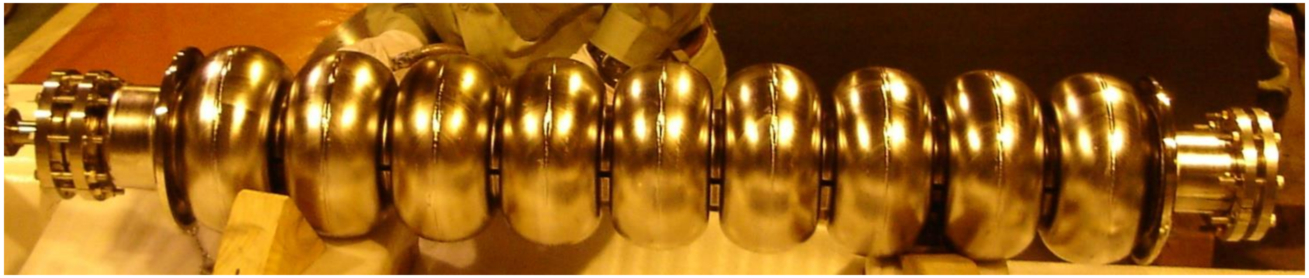
Beam

EBW of end-beam-pipes and cell-part

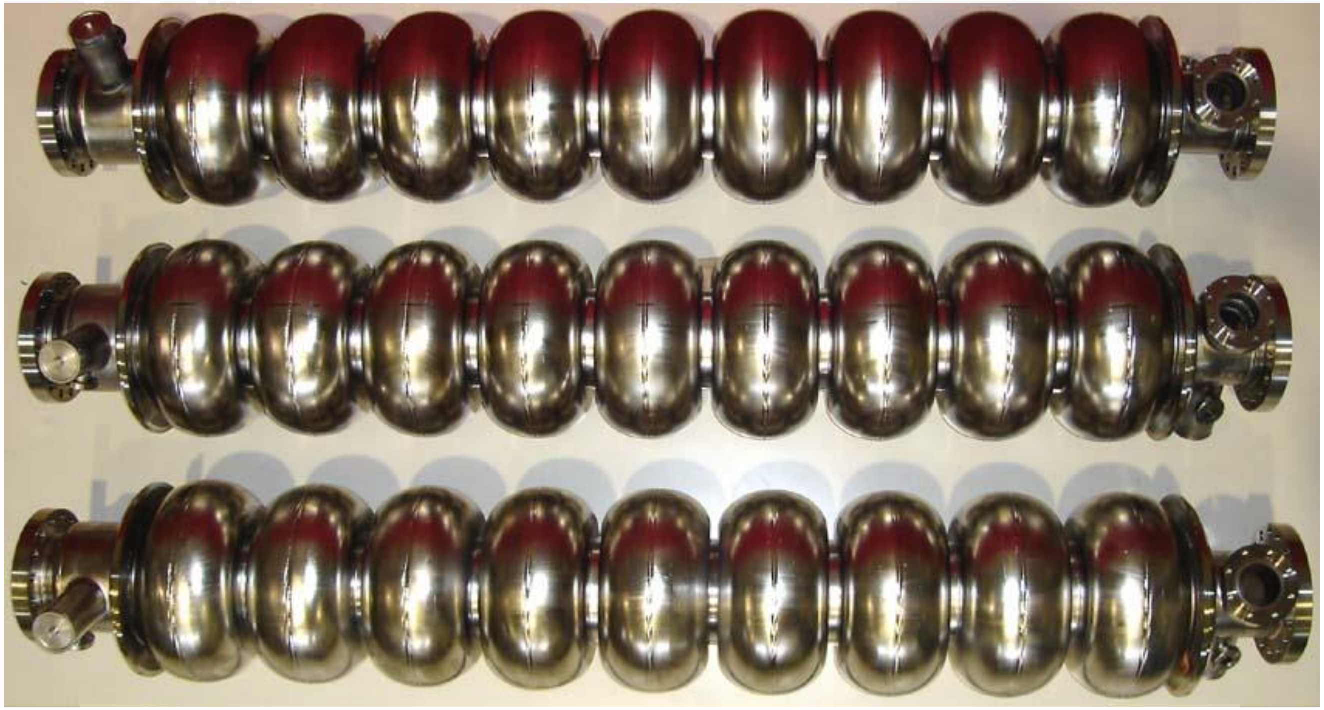


Delivery of 9-cell LL Cavities

1st, 2nd, 3rd, 4th LL 9-cell cavities



without HOM coupler

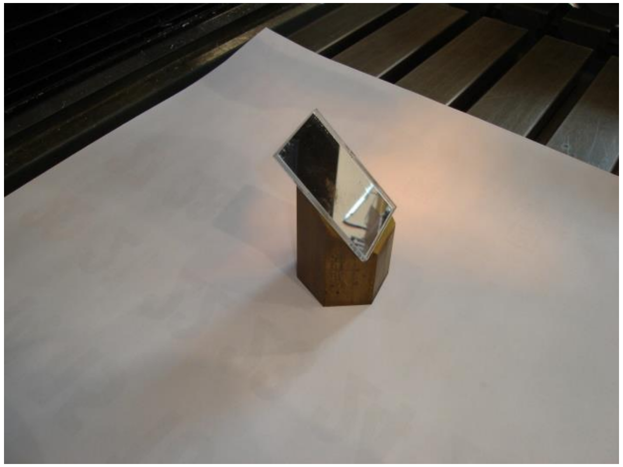


with HOM coupler

with HOM coupler

with HOM coupler

Shrinkage by EBW



	EBW shrinkage
iris	0.148+-0.044 mm
equator	0.424+-0.125 mm

Dimensional measurements

Length of the cavities were measured by 3D-measurement machine.

Dimensional deviation of length (only 9-cell part: 1038.5 mm)

-10 mm (1st 9-cell ICHIRO cavity) ← Without dumbbell tuning

- 0.7 mm (2nd 9-cell ICHIRO cavity)

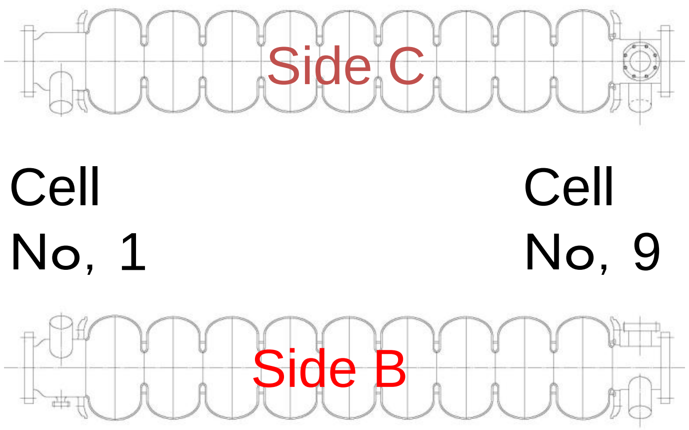
- 0.1 mm (3rd 9-cell ICHIRO cavity)

- 0.1 mm (4th 9-cell ICHIRO cavity)

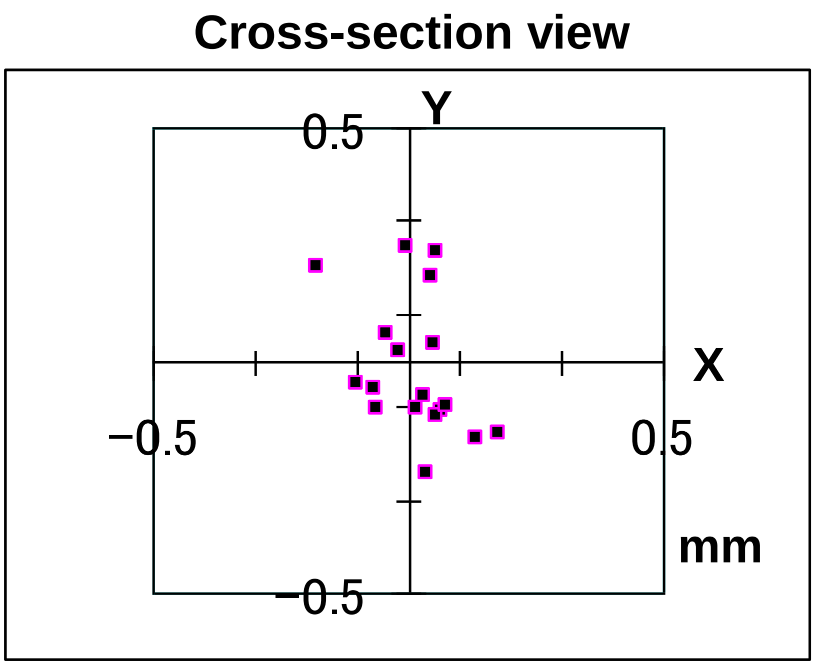
(2nd–4th) With dumbbell tuning

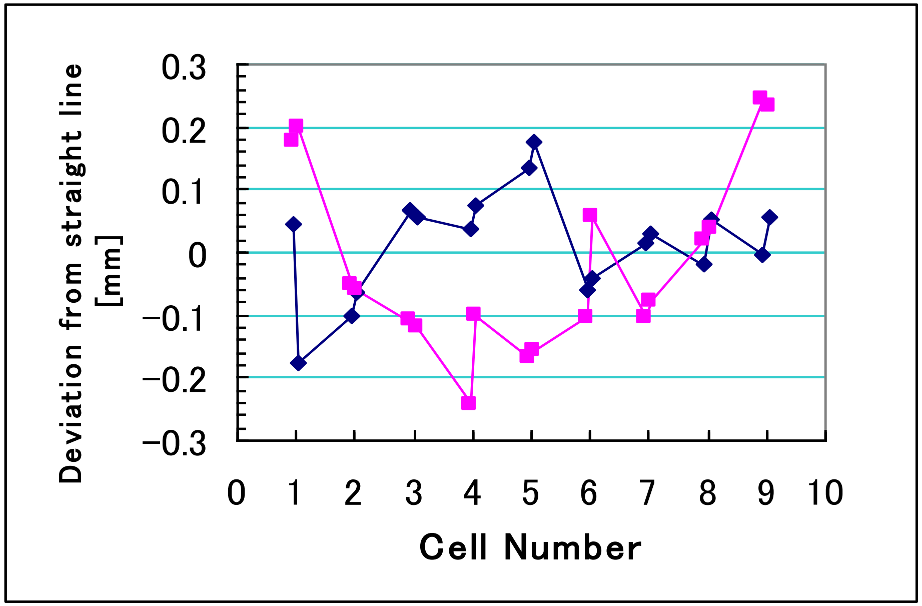
Operator learned how to tune the dumbbells and fabrication error became less than 0.1 mm !

Straightness



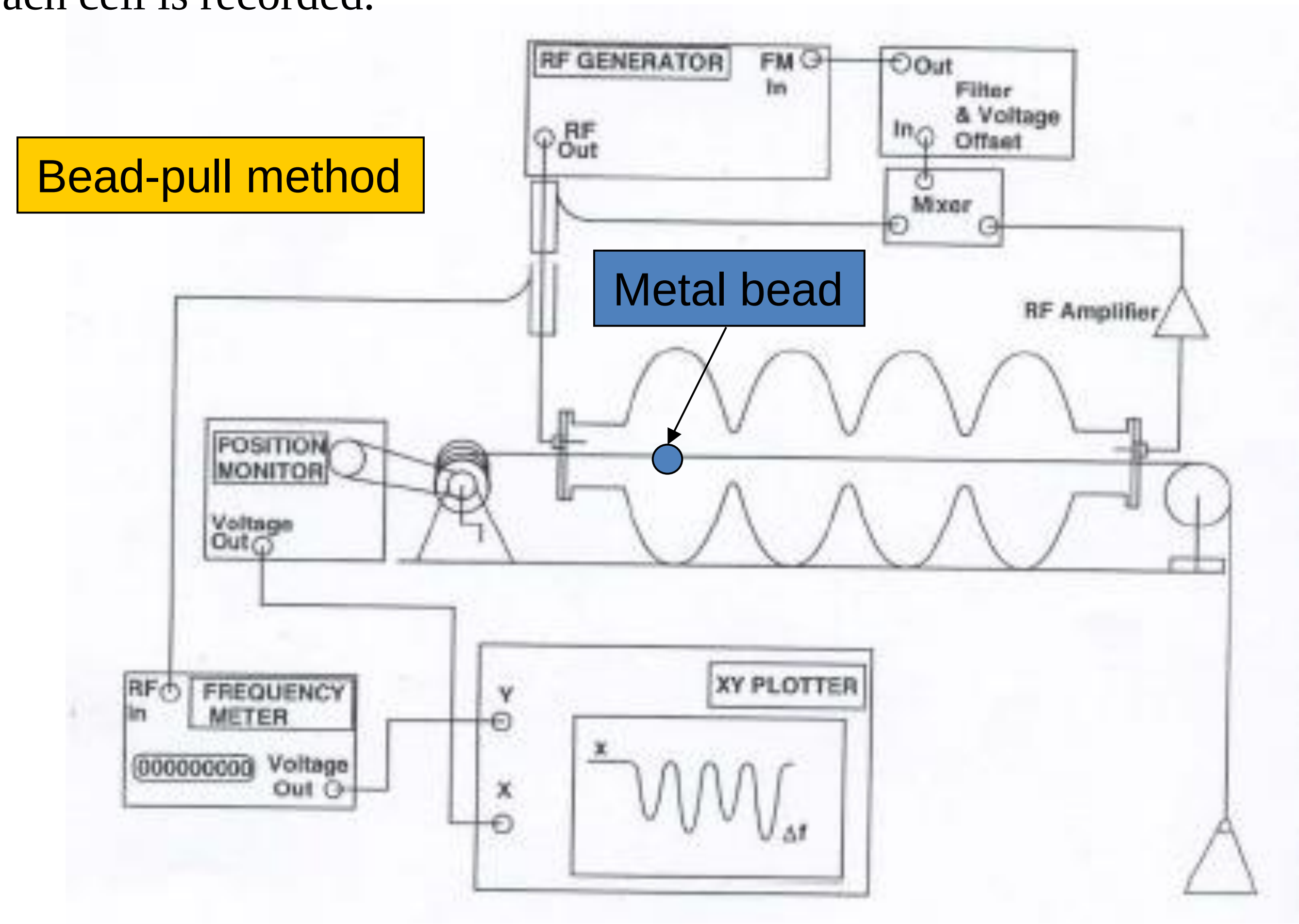
3-D measurements of straightness of cavity





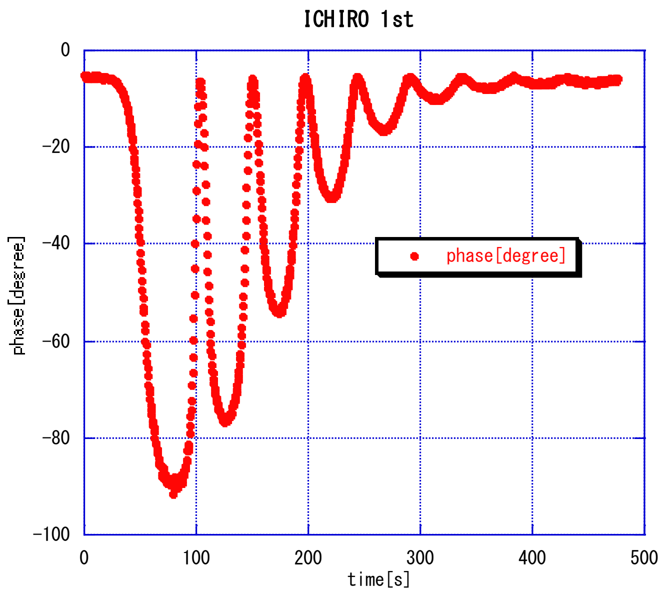
Pre-tuning for field flatness

Set-up for field profile measurements: a metallic needle is perturbing the rf fields while it is pulled through the cavity along its axis; the stored energy in each cell is recorded.



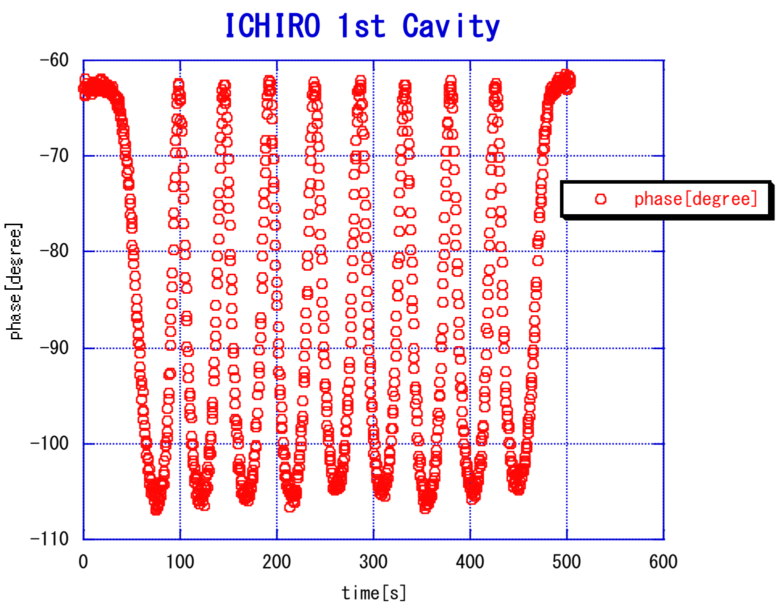
Filed flatness before/after pre-tuning

π mode frequency 1298.774 MHz



Field flatness = 0.1 %
(as delivered to KEK)

π mode frequency 1298.547 MHz

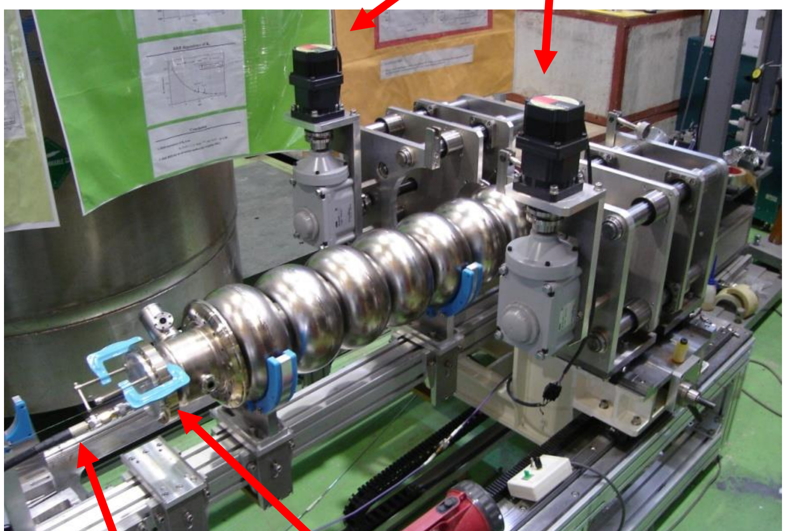


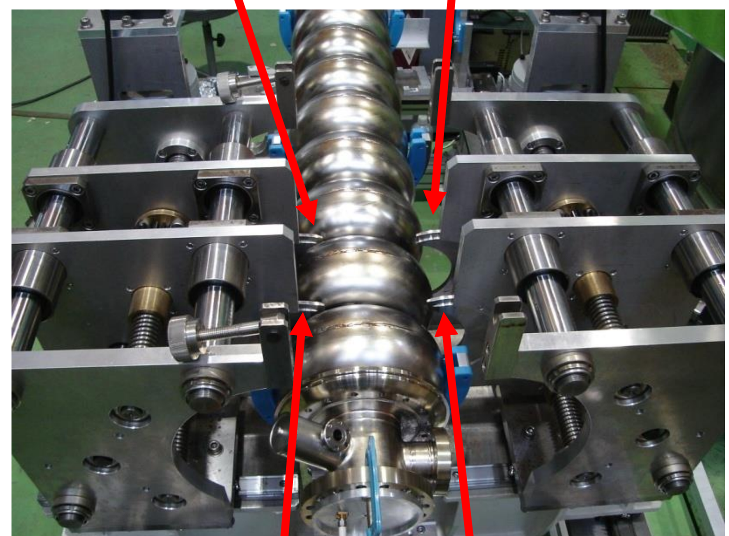
Field flatness = 98 %
(after pre-tuning)

Pre-tuning

Stepping-motor

Blades are inserted into the iris





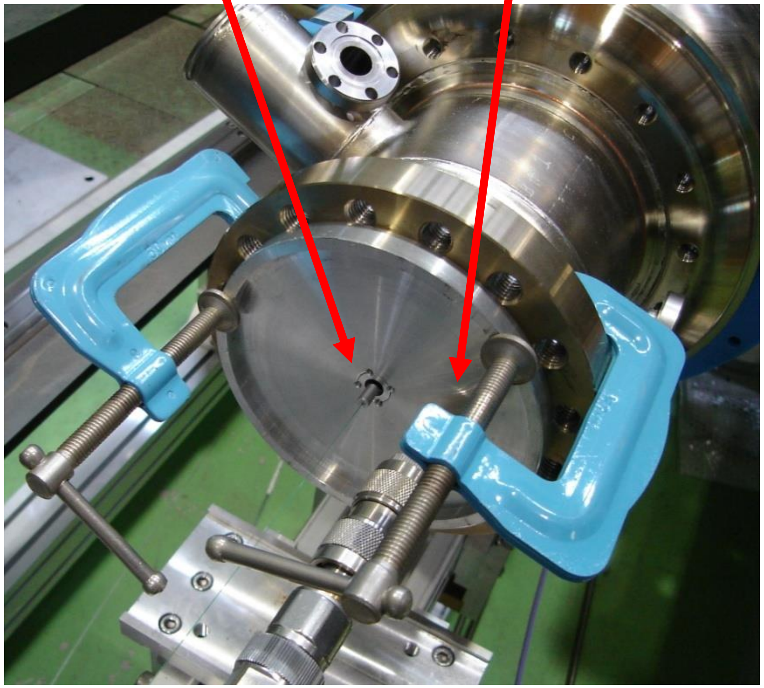
Flange with antenna

Blades are inserted into the iris

Line with metal bead

Pre-tuning

Metal bead Antenna



Pressing the cell by the blades